FINAL

GROUNDWATER CIRCULATION WELL PILOT TEST TECHNICAL MEMORANDUM

NORTHWEST PIPE AND CASING OPERABLE UNIT 2 GROUNDWATER REMEDIAL DESIGN

NW Pipe and Casing/Hall Process Company
Clackamas, Oregon

January, 2003

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Job Number: 33754159

Document Control Number: 9300.54

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1.0 INTRODUCTION AND OBJECTIVES

This technical memorandum describes the results of Groundwater Circulation Well (GCW) pumping tests that were conducted in September 2002 at the NW Pipe and Casing/Hall Process Company (NWPC) Superfund Site in Clackamas, Oregon (Figure 1). URS conducted these activities in support of the Remedial Design (RD) for Groundwater Operable Unit (OU) 2. The OU 2 selected remedy is described in the *Record of Decision* (ROD) for OU 2 [U.S. Environmental Protection Agency (EPA), 2001].

Historical mishandling of chlorinated solvent wastes generated during pipe-coating activities at the site resulted in contamination of groundwater with volatile organic compounds (VOCs). The ROD identifies three VOCs as Chemicals of Concern (COCs): tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride (VC). The COCs have been identified at four groundwater contaminant plumes, referred to as Plumes 1 through 4. The plume footprints, as defined by the 2002 PCE groundwater concentrations, are shown on Figure 2. The remediation goals (RGs), as specified in the ROD for PCE, TCE, and VC, are 1.0 μg/L, 1.6 μg/L, and 1.0 μg/L respectively. The selected remedy calls for the installation of GCWs, using in-well air sparging to treat and contain the most highly contaminated groundwater, and use of natural processes to address lesser-contaminated groundwater at the site.

Pumping tests were conducted at the following locations:

- A single-cell reverse-flow system (GCW-1) was conducted on the Oregon Department of Transportation (ODOT) property. This location is at the downgradient edge of commingled Plumes 1 and 4. This location is referred to as Pilot Test Site A (Figure 3).
- A single-cell reverse-flow system (GCW-2) was conducted on the former Hall Process Company (Parcel B) property. This location is within Plume 3, and is referred to as Pilot Test Site B (Figure 4).

The primary objectives of the pumping tests discussed in this report are to show that the selected in-situ remedial alternatives will be effective in reducing source area COC concentrations, and will provide an effective treatment wall to prevent COCs above the RGs from migrating off site. Specifically, the GCW technologies would be considered effective if:

- The GCW's circulation cell can be established under the site conditions;
- The circulation cells can be established to match the COC distribution at the site;
- The circulation cell flow characteristics can be measured and shown to be effective using pressure transducers (PTs); and
- The circulation cell is shown to have a reasonably sized hydraulic zone of influence (ZOI) to cost-effectively capture COCs.

The ability of GCWs to strip VOCs from groundwater is well documented. Therefore, the pilot test did not include testing of the stripping efficiency of the GCWs.

2.0 BACKGROUND

2.1 Site Description

The NWPC site lies within the lower Willamette River basin of western Oregon, in a north-south trending valley between Mount Talbert to the east and a low bluff to the west. The site is located between SE Lawnfield and SE Mather Roads in Clackamas County, Oregon, and is approximately 20 miles southeast of Portland (Figure 1). The CERCLIS ID number for this site is ORD 980988307. The site is adjacent to Southern Pacific Railroad tracks and is approximately one-half mile east of Interstate Highway 205.

The site is located in a mixed commercial and light industrial district. The Camp Withycombe Army National Guard facility is located to the immediate southeast of the site. Adjacent businesses to the east along Mather Road include metal salvage and related operations and a truck manufacturing facility. Property immediately east of the site, formerly an automobile junkyard, has now been redeveloped to include a commercial building. A small residential community known as Hollywood Gardens is located to the south of Camp Withycombe. The bluff west of the site is occupied by a collection of retail and commercial businesses concentrated along SE 82nd Avenue, including restaurants, motels, gas stations, stores and an elementary school.

The site covers approximately 53 acres of land. For purposes of the EPA's site management, the site was divided into two parts, Parcel A (21 acres) and Parcel B (32 acres), based on historical uses of the properties.

The valley in which the site is located is drained by Dean and Mount Scott Creeks, which flow to the north-northwest and eventually flow into the Willamette River. The site is flat, and lies at an approximate elevation of 105 feet NGVD. Standing water on Parcel B is common during the rainy season, as a result of poor drainage. Most of the surface water from Parcel B infiltrates into the ground. Some surface water may drain into a manmade ditch along the east boundary of the site, which subsequently drains into Dean Creek. A manmade ditch is present along the west boundary of the site. A low berm along the western site boundary prevents surface water from entering the ditch, except in the northwest corner where surface water can flow off-site during heavy rain events.

2.1.1 Geologic and Hydrogeologic Conditions

The site is located within the Portland Basin, a major sediment-filled depression found in the northern part of the Willamette River valley and adjoining the Columbia River valley. Geology of the area consists of coarse-grained Clackamas River fluvial deposits overlain by silt- and clay-rich flood deposits, such as those generated during the Missoula Flood of the Columbia River basin. The fluvial deposits are underlain by the Boring lavas. The uppermost regional unit is recent alluvium consisting of interbedded and variable silts, sands, and gravels.

Five distinct subsurface geologic units have been identified at the site.

Fill Unit

The uppermost unit is imported fill consisting of silty gravels extending from the ground surface to a depth of 1 to 3 feet.

Upper Silt Unit

This unit underlies the fill and consists of about 90 percent silt and clay and 10 percent sand. The silt typically extends to a depth of 4 to 10 feet.

Upper Gravel Unit

Underlying the Upper Silt Unit, this unit varies with depth from silty gravel in the upper portion to well-graded gravels and cemented gravels in the lower portion. The unit extends to a depth of about 90 to 110 feet.

Lower Silt Unit

This unit consists of silt, clay, and sandy silt. It lies beneath the Upper Gravel Unit, at a depth of 90 to 110 feet.

Lower Gravel Unit

This unit underlies the Lower Silt Unit, and extends to a depth of 136 feet. It consists of about 80 percent gravel with sand and a trace of fines.

Two aquifers systems are located beneath the site. The upper aquifer consists of the Upper Gravel Unit. It is artificially divided into shallow, intermediate, and deep zones based on the placement of monitoring well screen intervals. The lower aquifer consists of the Lower Gravel Unit. The lower aquifer appears to be artesian.

Groundwater flow in the upper aquifer is generally toward the north and northwest, with no significant seasonal changes in direction observed. Groundwater flow velocity in the upper aquifer at the site is estimated at 0.3 foot/day. The volume of groundwater flowing through the upper aquifer at the site is estimated to be 101,000 gallons/day. The groundwater flow direction in the lower aquifer is likely to the north as well.

2.1.2 Contaminants of Concern

As described previously, the three COCs, PCE, TCE, and VC, are located in four groundwater plumes. The plumes are within the shallow and intermediate portions of the upper aquifer. URS' *2002 Monitoring Well Installation and Groundwater Sampling Technical Memorandum* (URS, January 2003) describes the overall extent of contamination based on historic as well as recent (October 2002) groundwater data.

2.2 GCW System Descriptions

GCW technology involves the creation of vertical groundwater circulation cells by drawing groundwater through one screen section of a double-screened well and discharging it through the other screened section. This circulation pattern commonly occurs from the top of the formation to the bottom (herein termed standard flow). Under standard flow conditions, groundwater is directed upward inside the GCW. Groundwater flow upward through the GCW can be achieved via an air-lift effect, or it can be induced via an in-well groundwater circulation pump. In the standard flow mode, groundwater in the upper portion of the aquifer moves away from the GCW's upper screen while groundwater in the lower portion of the aquifer moves toward the GCW's lower screen.

In a reverse circulation mode, the flow of groundwater within the GCW is downward via the aid of an in-well groundwater pump. Groundwater in the lower portion of the aquifer moves away from the GCW's lower screen while groundwater in the upper portion of the aquifer moves toward the GCW's upper screen.

In both the standard- and reverse-flow modes of operation, groundwater is circulated around the GCW, but no groundwater is permanently extracted from the subsurface. The induced differences in potentiometric head establish and maintain a three-dimensional circulation cell in an ellipsoidal area around the GCW. The majority of groundwater captured in the capture zone of the circulation cell circulates a number of times through the GCW before being released downgradient. As such, groundwater serves as a carrier by bringing COCs from throughout the capture zone to the GCW, where it is treated via air-stripping. The groundwater then flows back into the aquifer. The vertical and horizontal circulation flow patterns force water to move through the entire aquifer portion within the circulation cell, thus improving COC mobilization by forcing flow through less permeable portions of the aquifer.

The total amount of water circulating around a GCW consists of: a) upgradient water being captured, and b) groundwater being recirculated prior to flowing downgradient and outside the ZOI. The relative proportion of captured water to re-circulated water is defined as the recirculation ratio (RR), and is an important design parameter related to the treatment of COCs. The flow dynamics and the dimensions of the capture zone, the circulation cell, ZOI, and the release zone are design elements that are calculated as part of the RD effort. This can be done either by numerical simulations of the groundwater hydraulics or by field-testing a full-scale GCW.

2.3 Preliminary Design Criteria for GCW Pumping Tests

2.3.1 Testing Location and Configuration

Pumping tests were conducted at two locations. Pilot Test Site A was selected to assess the ability of the GCW technology to contain the commingled Plumes 1 and 4. Pilot Test Site B was selected to assess the ability of the GCW technology to create a circulation cell suitable for source treatment. Plume 3 was selected for the latter study because of the relatively greater depth of contamination at this location. The thickness of the COC plumes at the site is such that the plume can be effectively address via a single cell GCW, which has one influent screen and one effluent screen.

The single cell GCW has two possible configurations: standard and reverse flow. Based on the site-specific conditions including the high water table, and the distribution of contaminants mainly within the shallow upper aquifer and to a lesser extent the intermediate upper aquifer, the most appropriate single circulation cell configuration at the site is reverse flow. If a "standard" flow circulation cell were used, this would reduce effectiveness of the GCW. Because of the shallow depth to groundwater, the GCW pumping rate would have to be reduced to prevent injected groundwater from mounding around the GCW and intersecting the ground surface. Pump testing of the reverse-flow single cell GCW configuration was therefore implemented.

2.3.2 Preliminary System Design Parameters

Prior to initiating the pump tests, the site-specific hydraulic configuration of the single cell GCW systems was calculated using the following data and assumptions:

Commingled Plumes 1 and 4 (Pilot Test Site A) Aquifer Input Parameters:

- Hydraulic gradient (i) = 0.004
- Effective porosity (n) = 30%
- Horizontal hydraulic conductivity (K_h)= 2.0 x 10-4 m/sec.
- Vertical hydraulic conductivity (K_v)= 2.0 x 10-5 m/sec.
- Groundwater flow direction is north.
- An internal groundwater recirculation rate (Q) of 10 gpm was proposed.
- Saturated thickness of 35 feet was proposed.

Plume 3 (Pilot Test Site B) Aquifer Input Parameters:

- Hydraulic gradient (i) = 0.001
- Effective porosity (n) = 30%
- Horizontal hydraulic conductivity (K_h)= 4.0 x 10-5
- Vertical hydraulic conductivity (K_v) = 4.0 x 10-6
- Groundwater flow direction is north.
- An internal groundwater recirculation rate (Q) of 20 gpm was proposed.
- Saturated thickness of 55 feet was proposed.

Assumptions:

- The aquifer thickness is constant, and the aquifer is under unconfined conditions.
- The aquifer structure is assumed to be radially isotropic with respect to hydraulic conductivity. Only one horizontal layer was used. The horizontal layer is anisotropic, with unique vertical and horizontal conductivities.
- Density effects were neglected, and steady-state conditions were assumed.

For estimating the capture zone, only convective transport was considered. Herrling's equations and graphical solutions for unconfined aquifers (Herrling and Stamm, 1992) were used, because the hydraulic gradient is small, and the rise in the static water level at the GCW during operation is minimal.

2.3.3 Preliminary Calculated Circulation Cell Parameters Prior To Pump Test

Based on the above aquifer data the following values for the various hydraulic dimensions of the two GCW systems were generated:

Preliminary Calculations for Commingled Plumes 1 and 4 Single Cell Reverse Flow GCW-1

- The upstream and downstream stagnation points (S) = 55 feet (Figure 5).
- The saturated thickness of the treatment zone (H) = 30 feet.
- The width B_b (groundwater capture zone at a distance 5H from the influent screen) = 200 feet.
- The width B_t (groundwater capture zone at a distance 5H from the effluent screen) = 7 feet.
- The effective hydraulic midpoint axis parallel to groundwater flow = 52 feet (95% of S).
- The effective hydraulic midpoint axis perpendicular to groundwater flow 95% of (Bb + Bt)/4 = 49 feet.
- The distance D (maximum spacing between GCW systems) = 104 feet.

Preliminary Calculation of Pore Volume Flush Time for Commingled Plumes 1 and 4 Single Cell Reverse Flow GCW-1

Pore volume flush time is defined as the time required for a unit volume of water to move from the effluent screen of the well, through the ZOI of the GCW system, and back into the influent screen of the well. This estimation of pore volume flush time does not take into account the variable groundwater velocity during the circulation path of a given molecule, because accelerated flow takes place closer to the well. Assuming 30% effective porosity, a molecule of water exiting each circulation cell would extend radially to a practical maximum distance of approximately 52 feet, and return to the GCW within approximately 365 days. Thus, with an effective midpoint axis parallel to flow (95% of S) of 52 feet the pore volume flush time would be approximately 365 days and at least one entire pore volume flush would have occurred within the circulation cell during one year of system operation (Stamm, 1995).

Preliminary Calculations for Plume 3 Single Cell Reverse Flow GCW-2

- The upstream and downstream stagnation points (S) = 224 feet.
- The saturated thickness of the treatment zone (H) = 50 feet.
- The width B_b (groundwater capture zone at a distance 5H from the influent screen) = 633 feet.
- The width B_t (groundwater capture zone at a distance 5H from the effluent screen) = 264 feet.

- The effective hydraulic midpoint axis parallel to groundwater flow = 100 feet (45% of S).
- The effective hydraulic midpoint axis perpendicular to groundwater flow 45% of (Bb + Bt)/4 =102 feet.
- The distance D (maximum spacing between GCW systems) = 448 feet.

Preliminary Calculation of Pore Volume Flush Time for Plume 3 Single Cell Reverse Flow GCW-2

Pore volume flush time is defined as the time required for a unit volume of water to move from the effluent screen of the well, through the ZOI of the GCW system, and back into the influent screen of the well. This estimation of pore volume flush time does not take into account the variable groundwater velocity during the circulation path of a given molecule, because accelerated flow takes place closer to the well. Assuming 30% effective porosity, a molecule of water exiting each circulation cell would extend radially to a practical maximum distance of approximately 100 feet, and return to the GCW within approximately 365 days. Thus, with an effective midpoint axis parallel to flow (45% of S) of 100 feet the pore volume flush time would be approximately 365 days and at least one entire pore volume flushes would have occurred within the circulation cell during one year of system operation (Stamm, 1995).

2.4 Static and Dynamic Head Measurements

PTs were used to measure static head and head changes in piezometers located across gradient from each GCW. A water level meter and PTs were used to measure static water level and head measurements within the GCW during the pump test.

In-situ Professional Mini-troll (30 PSI) vented PTs were used to measure static head and head changes during the pump test. The PTs were placed in the commingled Plumes 1 through 4 piezometers (Site A) and Plume 3 piezometers (Site B) at 20 feet and 15 feet respectively below top of casing. PTs were placed in GCW-1 and GCW-2 at 20 feet below the land surface.

The 30 PSI PTs have a resolution of 0.00531% of the full scale (0.001593 PSI), and an accuracy of plus or minus 0.1% of the full scale (0.03 PSI).

3.0 FIELD PROCEDURES

3.1 New Observation Piezometers

Piezometers were used to measure changes in head at various operating conditions of the GCWs. Pilot Test Site A piezometers (PZ-14 through PZ-19) (Figure 3) were installed perpendicular to groundwater flow relative to GCW-1 and at distances of approximately 57 percent, 130 percent and 198 percent of the preliminary practical hydraulic midpoint axis. The hydraulic midpoint axis perpendicular to groundwater flow (Bb + Bt)/4 in the preceding calculations above (i.e. the preliminary practical ZOI perpendicular to groundwater flow) was 47 feet for GCW-1.

Pilot Test Site B piezometers (PZ-20 through PZ-25) (Figure 4) were installed perpendicular to groundwater flow relative to GCW-2 and at distances of approximately, 23 percent, 45 percent and 68 percent of the preliminary practical hydraulic midpoint axis perpendicular to groundwater flow. The hydraulic midpoint axis perpendicular to groundwater flow (Bb + Bt)/4 in the preceding calculations above was 102 feet for GCW-2.

The Site A and Site B piezometers were constructed as shown on Table 1 and Appendix A. Site A and Site B piezometers were installed by drilling a 6-inch diameter borehole to approximately 20 and 45 feet below ground surface (bgs), and 20 and 65 feet bgs respectively. The piezometers were installed with appropriate sand packs and bentonite slurry seals between each screen interval. The piezometers were constructed of 2-inch-diameter PVC casing and slotted (0.020-inch slot size) PVC screens. The piezometers were developed after installation using standard well development procedures.

3.2 Installation of the GCW

GCW-1 was installed in a grass median between the ODOT parking lot and Lawnfield Road (Site A). The well construction is shown on Table 1 and Appendix A. The well was installed by drilling a borehole to accommodate a 10-inch well casing to a depth of 45 feet bgs using air rotary drilling methods. Upon completion of the borehole, the GCW was constructed by placing a 10-inch-diameter, low carbon steel casing and stainless steel screens into the borehole. The open borehole around the GCW was then packed with sand, and bentonite slurry seals were set at the appropriate depths. The upper screen was positioned between 15 to 25 feet bgs, and the lower screen was positioned between 35 to 45 feet bgs.

GCW-2 was located at Plume 3 (Site B). The well construction is shown on Table 1 and Appendix A. The well was installed by drilling a borehole to accommodate a 10-inch well casing to a depth of 65 feet bgs using air rotary drilling methods. Upon completion of the borehole, the GCW was constructed by placing a 10-inch-diameter Schedule 40 PVC casing and stainless steel screen into the borehole. The open borehole around the GCW was then packed with sand, and bentonite slurry seals were set at the appropriate depths. The upper screen was positioned between 15 to 25 feet bgs, and the lower screen was positioned between 55 to 65 feet bgs.

The screens consisted of 10-inch-diameter stainless steel Johnson "V" wire-wrapped screens. The 20-slot screen size was selected based on visual observations of grain size at the site. The GCWs were developed by surging and pumping water through each of the screened sections.

3.3 GCW Pumping Test Configuration

In-well treatment components (i.e. air-stripping unit) were not installed as part of the pump test because the objective of the test was to validate the hydraulics of the GCW technology as opposed to demonstrating the ability of the GCWs to strip COCs from groundwater. If the GCW technology is viewed favorably based on the result of the Pilot Test, the actual treatment technology will be chosen and designed based upon the hydraulic data collected during the tests and historic groundwater chemistry. The test configurations are described in the following discussion.

An inflatable high-pressure roll-up plug (packer) assembly (Model 40-06-1) was used in both pumping tests. The packer had inflatable seals resistant to organic hydrocarbons. The packer is designed for a well casing ID from 9 inches to 10.25 inches, and had a 10-inch-long element seal. The packer sealed the inside of the 10-inch GCW casing at an inflation pressure of 80 psi, thereby isolating the two screened sections of the GCW. The packer was fitted with an inflation kit that provided a port to introduce compressed air. The kit also contained a pressure gauge to monitor packer pressure (to evaluate if the packer maintained a proper seal).

3.3.1 Reverse Flow GCW Pumping Test

For the reverse-flow GCW pumping test, a pump was used to circulate groundwater in a reverse circulation pattern within the upper and lower screen sections of the GCW. To avoid short-circuiting within the well, the upper and lower screens were separated by an inflatable packer inside a solid section of well casing. To avoid short-circuiting in the borehole annulus a bentonite seal was placed in the borehole annulus around the solid section of casing separating the upper and lower screens. The circulation pattern consists of a circulation flow cell where groundwater enters the upper screen and exits through the lower screen. The single cell reverse flow GCW system used a submersible pump (intake located above the upper screen) to recirculate groundwater.

A PT and a pressure gauge were installed with the GCW to measure changes in the total head between the upper and lower screens. The upper PT was installed in the borehole annulus within the upper screened section, and the pressure gauge was installed in the injection line to the lower screened section.

3.3.2 Recirculation Pump, Piping and Instrumentation

A Grundfos 16-S submersible groundwater pump was used to move groundwater from the upper screened section to the lower screened section of the well. The water was pumped through a 2-inch-diameter PVC/HDPE pipe from the pump to the top of the well. A flow meter within the piping loop above the well head was used to measure the pumping rate and the total circulation flow rate of groundwater. The groundwater was then returned to the well and discharged through the lower screen. Total head changes inside the GCW were measured by using a PT installed in the shallow well annulus to measure pressure in the upper zone of the well, and a pressure gauge on the reinjection line to measure pressure in the lower screen of the well. A pressure gauge was installed on the influent line to determine back pressure on the submersible pump and injection line.

3.4 Installation of Pressure Transducers in Piezometers

Six PTs were installed in the observation piezometers (three sets of two piezometers at each test location). Prior to installation in the field, the depth to water surface was measured in each of the observation piezometers. The PTs were then positioned at an appropriate depth below the water surface in their respective piezometers. Water level data were recorded with a data logger. The data logger was programmed to collect a water level reading at 15-second intervals.

4.0 GCW PUMPING TEST RESULTS

4.1 Reverse Flow GCW Pumping Test

The first objective during the pumping test was to determine if circulation at equilibrium could be achieved. GCW-1 was pumped at 22 liters/min (5.8 gpm), 25 liter/min (6.6 gpm), and 33 liter/min (8.7 gpm). Equilibrium was established at the first two rates but not the third. GCW-2 was pumped at rates of 19 liters/min (5 gpm), 47 liter/min (12.4 gpm), and 70 liter/min (18.5 gpm). Equilibrium was established at all three pumping rates. Equilibrium was reached within several minutes after the initiation of pumping at both locations.

The second objective was to operate the GCWs at various flow rates to determine the maximum and minimum circulation flow rate at equilibrium. Based on the two-inch pipe flow capability for influent and effluent flow, and the depth of the submersible pump (17 feet below top of casing at GCW-1, and 20 feet below top of casing at GCW-2) the maximum equilibrium pumping rate was 25 liters/min (6.6 gpm), and 60 liters/min (15.8 gpm) for GCW-1 and GCW-2 respectively. The minimum flow rate is based on the ability of the cell to avoid preferential flow pathways within the aquifer. These pathways may reduce the ZOI considerably, and do not allow for a 360 degree pore volume flush through the ZOI. The minimum flow for GCW-1 and GCW-2 was based on achieving a head differential at 25 percent of the ZOI. This was accomplished when the cell was being pumped at 22 liters/min (5.8 gpm), and 19 liters/min (5 gpm) for GCW-1 and GCW-2 respectively.

The third objective was to establish the ZOI of the GCW. This objective was determined mathematically and empirically. The mathematical method used the GCW input parameters determined by construction, measurement, and operation during the pumping test to recalculate the GCW ZOI parameters. The empirical method was to determine the ZOI based on changes in head at the piezometers located across gradient at various distances relative to the anticipated ZOI (calculated based on previous assumptions and measurements of aquifer parameters).

Tables 2 and 3 show the GCW input parameters for GCW-1 and GCW-2, and the method for determining the input parameters. Mathematical determination of the GCW-1 and GCW-2 ZOI used the pumping test input parameters to recalculate the GCW-1 and GCW-2 ZOI parameters (Tables 4 and 5).

The empirical method for determining the GCW ZOI used the recorded equilibrium head differentials at the various piezometers to establish the GCW cell boundaries at GCW-1 and GCW-2. The GCW-1 PTs were set in piezometer pairs at the projected distances of 57 percent, 130 percent, and 198 percent of the estimated circulation axis perpendicular to groundwater flow. The piezometer pairs facilitated the measurement of the presence or absence of head differential readings based on the pumping of GCW-1. Piezometer data are presented in Appendix B. The maximum head differentials at equilibrium that showed a vertical gradient upward for GCW-1 were piezometer pairs PZ-14/PZ-15 (0.61 meter head differential at 6.6 gpm at 32 feet from GCW-1), and PZ-16/PZ-17 (0.4 meter head differential at 6.6 gpm at 64 feet from

GCW-1). The piezometer pair PZ-18/PZ-19 did show a vertical gradient upward, but did not appear to reach equilibrium at any pumping rate. The estimated head differential at PZ-18/PZ-19 was 0.23 meters at 6.6 gpm at 96 feet from GCW-1. The equilibrium vertical-upward gradient for GCW-1 indicated that the ZOI maximum boundary for the circulation cell was being set up between the PZ-16/PZ-17 and PZ-18/PZ-19 piezometer pairs.

The GCW-2 PTs were placed in piezometer pairs set at the projected distances of 23 percent, 45 percent, and 68 percent of the estimated circulation axis perpendicular to groundwater flow. The piezometer pairs allowed for the measurement of the presence or absence of head differential readings based on the pumping of GCW-2. The maximum head differentials at equilibrium that showed a vertical gradient upward for GCW-2 were piezometer pairs PZ-20/PZ-21 (2.30 meter head differential at 15.8 gpm at 23 feet from GCW-2), PZ-22/PZ-23 (0.178 meter head differential at 15.8 gpm at 46 feet from GCW-2), and PZ-24/PZ-25 (0.125 meter head differential at 15.8 gpm at 69 feet from GCW-2). The equilibrium vertical-upward gradient for GCW-2 indicated that the maximum boundary for the circulation cell was being set up beyond the PZ-24/PZ-25 piezometer pair.

The strength of the head differential is based on the distance from the GCW well, heterogeneities or anisotropic conditions in the aquifer, and the piezometer screen horizons as compared to the screen horizons of the GCW.

4.2 Zone of Influence and Capture Zone Data Analysis

4.2.1 Single Cell Reverse Flow GCW Mathematical Zone of Influence for GCW-1

The data from the GCW-1 pumping test were used to adjust the preliminary calculated predictions (section 2.3) for the ZOI and the associated capture zone of GCW-1 to more accurately determine the GCW circulation cell and capture zone parameters (Table 2). The recalculated parameters show a maximum midpoint axis parallel to ground water flow (S) of 75 feet, and a maximum midpoint axis perpendicular to groundwater flow (Bb + Bt)/4 of 74 feet (See Table 4). The recalculated capture zone shows a maximum top width (Bb) of 233 feet and a minimum bottom width (Bt) of 64 feet.

4.2.2 Single Cell Reverse Flow GCW Mathematical Zone of Influence for GCW-2

The data from the GCW-2 pumping test was used to adjust the preliminary calculated predictions (section 2.3) for the ZOI and the associated capture zone of GCW-2 to more accurately determine the GCW circulation cell and capture zone parameters (Table 3). The recalculated parameters show a maximum midpoint axis parallel to ground water flow (S) of 239 feet, and a maximum midpoint axis perpendicular to groundwater flow (Bb + Bt)/4 of 254 feet (See Table 5). The recalculated capture zone shows a maximum top width (Bb) of 645 feet and a minimum bottom width (Bt) of 371 feet.

4.3 Time of Circulation Analysis

4.3.1 Single GCW Practical Zone of Influence

The time of circulation calculation for GCW-1 and GCW-2 provides the practical ZOI for the single cell reverse flow GCWs. The practical ZOI is based on one pore volume flush in 365 days (Stamm, 1995). The percentages of "S" and "(Bb + Bt)/4" are determined by the 365-day limit line as it intersects the 30% porosity line of the aquifer for GCW-1 (Figure 6) and GCW-2 (Figure 7). For GCW-1, 98% of the midpoint axis parallel to flow ("Practical" S) is 74 feet, and 98% of the midpoint axis perpendicular to flow ["Practical" (Bb + Bt/)4] is 73 feet. For GCW-2, 40% of the midpoint axis parallel to flow (Practical S) is 96 feet, and 40% of the midpoint axis perpendicular to flow [Practical (Bb + Bt/)4] is 102 feet. The maximum practical ZOI for GCW-1 and GCW-2 are summarized on Table 6.

4.3.2 Single GCW Practical Zone of Capture

The practical capture zone of a single GCW is based on 100 percent of the capture zone area as defined by the trapezoid "Bb" and "Bt" (Figure 8). If a single GCW is used as a treatment wall, the time of capture calculation is not an issue. Instead, the ability of the wall to stop all of the COCs from migrating downstream beyond the wall becomes the major factor. In this case, 100% of the capture zone area as defined by the trapezoid "Bb" and "Bt" can be used.

4.3.3 Capture Zone Determination For Two or More GCW Wells

When two or more GCW wells are in a line perpendicular to ground water flow, the capture zone for multiple GCWs is defined by multiples of "D". "D" is the maximum spacing between two GCWs that can be achieved without breakthrough of the COC plume. The D spacing is calculated as 2 x (Bb + Bt)/4. The (Bb + Bt)/4 dimension for GCW-1 and GCW-2 is 74 feet and 254 feet respectively. The D spacing is 148 feet for GCW-1 and for 508 feet for GCW-2 (Tables 4 and 5). The maximum capture zone for two or more GCWs is calculated as 2 x (Bb + Bt)/4 + [(number of GCWs – 1) x D] (Figure 9).

5.0 POTENTIAL FOR GCW FOULING DURING OPERATION

5.1 Incrustation Potential of the Well and Air Stripper

The potential for incrustation of groundwater well casings and screens may be estimated by considering several parameters that characterize the inorganic groundwater quality. These parameters include: pH, concentrations of dissolved gases (i.e., oxygen, and carbon dioxide), total dissolved solids, carbonate hardness, iron, and manganese.

Potentially incrusting conditions are indicated by high pH, high carbonate hardness, and significant levels of iron and manganese.

The potential for carbonate incrustation, or scaling, can be evaluated by considering the relative saturation level of calcite. Methods for estimating calcite saturation include the graphical method of Morel and Hering (1993), Langelier's (1936) saturation index, Ryznar's (1944) stability index, the saturation indices described by Lloyd and Heathcote (1985), and a thermodynamic approach developed by Snoeyink and Jenkins (1980). A complete characterization of groundwater geochemistry can be obtained using the software developed by Allison, *et al.* (1991).

An evaluation of incrustation potential at the site was completed using the Ryznar Stability Index (RSI). The RSI predicts the corrosive or incrusting tendencies of a particular water. It is widely used for predicting the reaction of solid metals in saturated conditions. A water is corrosive if the index is higher than 7 and incrusting if lower than 7. The RSI is calculated based on alkalinity, total dissolved solids, total calcium, and pH data using the following formula:

$$I = S - C - pH$$

where I is the RSI value, S is a factor derived from a standard curved developed for total dissolved solids data, and C is a factor based on a standard curve developed for alkalinity and total calcium data.

The analytical results for the RSI parameters and the calculated RSI values are summarized in Table 7. The RSI values for all four plumes range from 6.56 to 9.80. The results of the Ryznar Index indicate no potential for carbonate incrustation at the present naturally occurring groundwater geochemistry in all but the worse-case well (MW-5). Monitoring well MW-5 indicates a slight potential for carbonate incrustation. The Ryznar Index does indicate a potential for corrosion at the present naturally occurring groundwater geochemistry in all wells except MW-5. Corrosion of wells is not a concern as the well casing, well screens, and piping will be constructed of PVC, stainless steel, and HDPE, which are not effected by corrosion.

The *Remedial Design Strategy Technical Memorandum* (URS, May 2002) calculated RSI values based on historic analytical data for the site. The results ranged from 7.9 to 8.6. The technical memorandum incorrectly stated that these values indicated a potential for "inorganic fouling" (i.e. incrustation). In fact, these values indicate a potential for corrosion, which is consistent with the RSI values shown on Table 7.

The potential for iron and manganese precipitation/incrustation at vertical circulation well sites, where in-situ vacuum based air stripping is used as the treatment, has required quarterly cleaning of the air stripper at levels of 20 mg/l or higher of dissolved iron and manganese. The combined total concentrations of dissolved iron and manganese at the site have shown a maximum concentration of 5.98 mg/l (Table 8), which is well below the level where quarterly cleaning of the air stripper has been required.

The potential for carbonate, iron, and manganese incrustation is low at the site under naturally occurring groundwater geochemical conditions. The geochemical conditions will be changed by vertically circulating groundwater and by the treatment method (air stripping). The geochemical and physical components that will change are the raising of the pH (degassing of carbon dioxide), addition of oxygen, and turbulence in the well, sand pack and air stripper. These geochemical changes may cause a decrease in the Ryznar index, and oxidation of iron and manganese leading to some precipitation of carbonate, iron and manganese mainly in the air stripper, and not in the well or aquifer formation.

5.2 Biofouling Potential of the Well and Air Stripper

Operation of GCWs may stimulate the biotransformation of organic carbon substrates (VOC, etc.) in various zones, which will evolve within the GCW's radius of influence. These zones will be characterized by their redox potential and availability of organic carbon substrates. Some organic compounds may be biotransformed by terminal electron accepting processes including oxidative respiration, denitrification, sulphate reduction, methanogenesis, and iron reduction. Chlorinated hydrocarbons may be biotransformed by reductive dechlorination, cometabolism, and oxidative respiration. The character and extent of biotransformation are a function of redox potential, availability of organic carbon substrates, and the microbial community. These factors, in turn, are dependent on characteristics of the aquifer and the installation and operation of the GCW. Groundwater sampling for substrate concentrations and concentrations of suspended microbes are not sufficient to characterize and quantify the potential extent of biotransformation and the concomitant production of biomass in the GCW's ZOI. Accumulation of attached biomass (biofouling) on aquifer material may significantly reduce the effective hydraulic conductivity. This in turn will reduce the effectiveness of the GCW.

The potential for incrustation/precipitation or biofouling under naturally occurring groundwater geochemistry is minimal at the site. The level of incrustation/precipitation or biofouling in a remediation system (well and treatment unit) under dynamic (operating) conditions is not known with certainty, but the likelihood of significant problems is not evident.

6.0 CONCLUSIONS

6.1 Summary of GCW Operational Parameters

The pilot test results indicate that GCWs will be effective in reducing source area COC concentrations, and will provide an effective treatment wall to prevent COCs above the RGs from migrating off site (at the downgradient edge of commingled Plumes 1 and 4). The final GCW placement is proposed in the Basis of Deign report, which is being prepared as part of the overall RD package. This section summarizes the overall GCW operational parameters that will be used for selecting GCW locations. The GCW Operational parameters are summarized on Table 9. Note that the pumping rates recommended below are based on pilot testing. During installation of the remedy, actual pumping rates will be determined at the startup/shakedown phase of the GCWs, and may vary from those recommended below, based on the subsurface conditions encountered at each GCW location.

6.1.1 Treatment Wall Operational Parameters, Commingled Plumes 1 and 4

When used as a treatment wall, the important operational parameters are pumping rate, D spacing, and the midpoint axis perpendicular to flow [(Bb + Bt)/4]. The GCW-1 pumping test results indicated an optimum pumping rate of 6.6 gpm. The D spacing is 148 feet. The midpoint axis perpendicular to flow is 74 feet. The capture zone width of a 3-GCW treatment wall would be 2 x (Bb + Bt)/4 + [(number of GCWs-1) x D] = 444 feet.

6.1.2 Source Reduction Operational Parameters, Plumes 1 and 4

When used for source reduction, the important operational parameters are pumping rate, the practical midpoint axis parallel to flow (Practical S), and well spacing. A GCW pilot test was not conducted within the most highly contaminated portions of Plumes 1 and 4. The GCW-1 pilot test results have been used for selecting the operational parameters, as these values are more conservative than the results at GCW-2. The GCW-1 pumping test results indicated an optimum pumping rate of 6.6 gpm. Practical S is 74 feet. An individual GCW would have a ZOI extending outward 74 feet from the GCW. The spacing between two or more GCWs placed perpendicular to groundwater flow would be 2 x Practical S = 148 feet. The capture zone for two or more GCWs placed perpendicular to groundwater flow would be 2 x Practical S x (number of GCWs). For example, two GCWs would have a capture zone of 2 x 74 x 2 = 296 feet.

6.1.3 Source Reduction Operational Parameters, Plume 2

A pilot test was not conducted at Plume 2. The nearest pilot test is at GCW-2 at Plume 3, where a Practical S value of 96 feet was calculated, which is greater than the 74-foot Practical S value calculated at GCW-1. Because a pilot test was not conducted at Plume 2, the 74-foot value has been used to determine GCW spacing as a conservative approach. Similarly, the lower 6.6 gpm pumping rate at GCW-1 is recommended.

6.1.4 Source Reduction Operational Parameters, Plume 3

The GCW-2 pumping test results indicated an optimum pumping rate of 18.5 gpm. Practical S is 96 feet. An individual GCW would have a ZOI extending outward 96 feet from the GCW. The spacing between two or more GCWs placed parallel to groundwater flow would be 2 x Practical S = 192 feet. The capture zone for two or more GCWs placed perpendicular to groundwater flow would be 2 x Practical S x (number of GCWs). For example, two GCWs would have a capture zone of 2 x 96 x 2 = 384 feet.

6.2 Comparison of Pilot Test Results with Preliminary Model

URS' *Remedial Design Strategy Technical Memorandum* included a preliminary model that calculated GCW operational parameters based on site specific hydrogeologic data, and assumptions regarding anticipated pumping rates, screen intervals, and other variables. The preliminary model results are shown on Table 9. The following discussion compares the preliminary model results to the pilot test results.

For a treatment wall at commingled Plumes 1 and 4, the preliminary model calculated a D spacing of 256 feet at a pumping rate of 20 gpm and a saturated thickness of 45 feet. The pilot test resulted in a D spacing of 148 feet at a pumping rate of 6.6 gpm and a saturated thickness of 30 feet. The preliminary model result for D spacing is larger because of the larger saturated thickness and higher pumping rate.

For source reduction at commingled Plumes 1 and 4, the preliminary model calculated a Practical S value of 55 feet, compared to the pilot test value of 74 feet. This would result in a well spacing of 110 feet. The preliminary model used an assumed pumping rate of 20 gpm. The actual pilot test ideal pumping rate was 6.6 gpm. The larger S value and lower pumping rate for the pilot test suggests that the hydraulic conductivity is somewhat lower than anticipated (based on historic hydrogeologic data).

Pilot testing was not conducted at Plume 2. The preliminary model predicted a Practical S value of 98 feet using a pumping rate of 20 gpm. This would result in a well spacing of 196 feet.

For Plume 3, the preliminary model calculated a Practical S value of 92 feet, compared to the pilot test value of 96 feet. The preliminary model used an assumed pumping rate of 20 gpm. The actual pilot test ideal pumping rate was 18.5 gpm. Overall, the preliminary model and pilot test results are quite comparable, suggesting that the preliminary modeling assumptions match the actual conditions at Plume 3.

At Plume 4, the preliminary model predicted a Practical S value of 58 feet using a pumping rate of 20 gpm. At the nearby GCW-1 pilot test, the actual ideal pumping rate was 6.6 gpm, and the Practical S value was 74 feet, again attributed to a lower than anticipated hydraulic conductivity.

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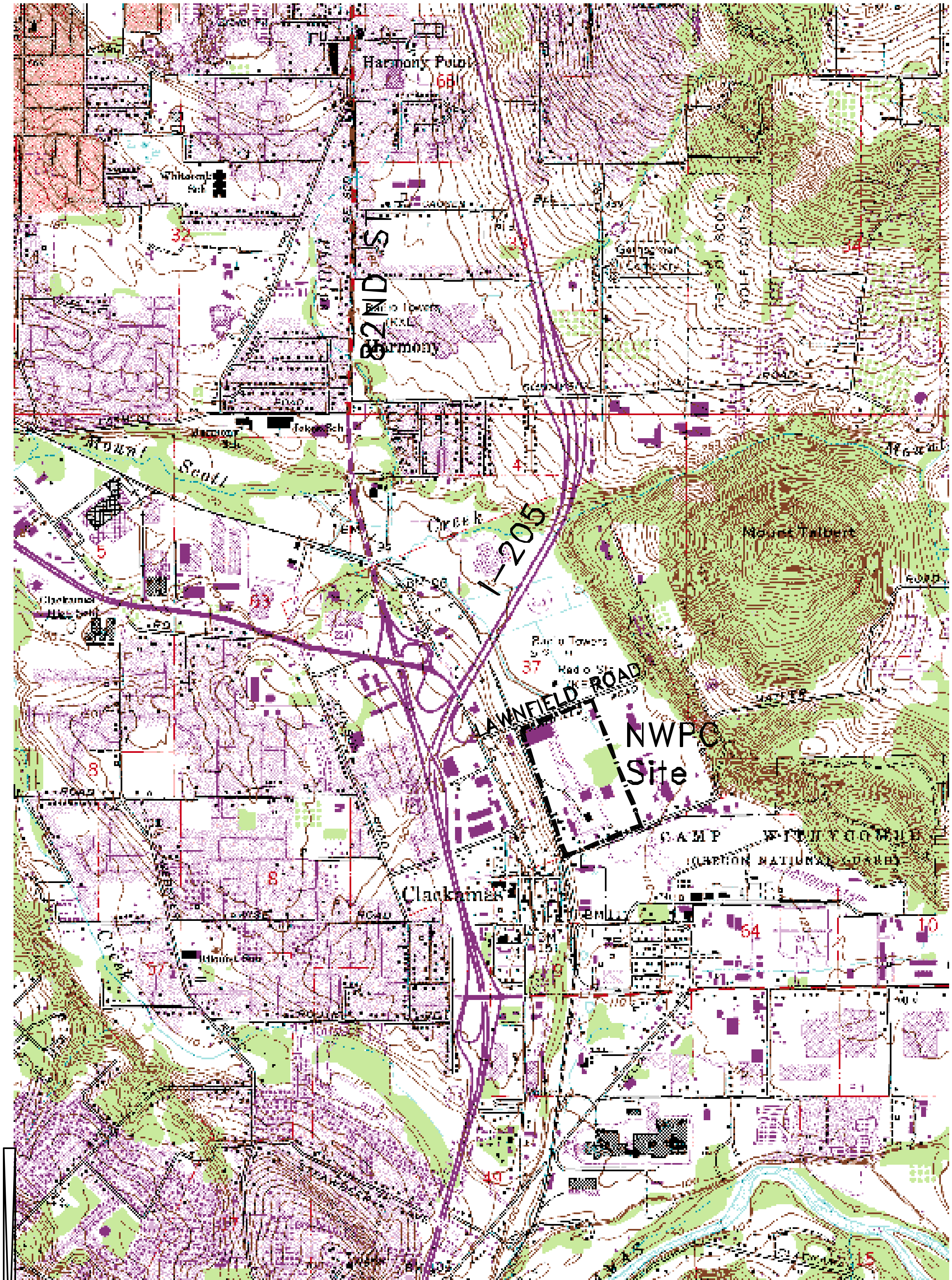
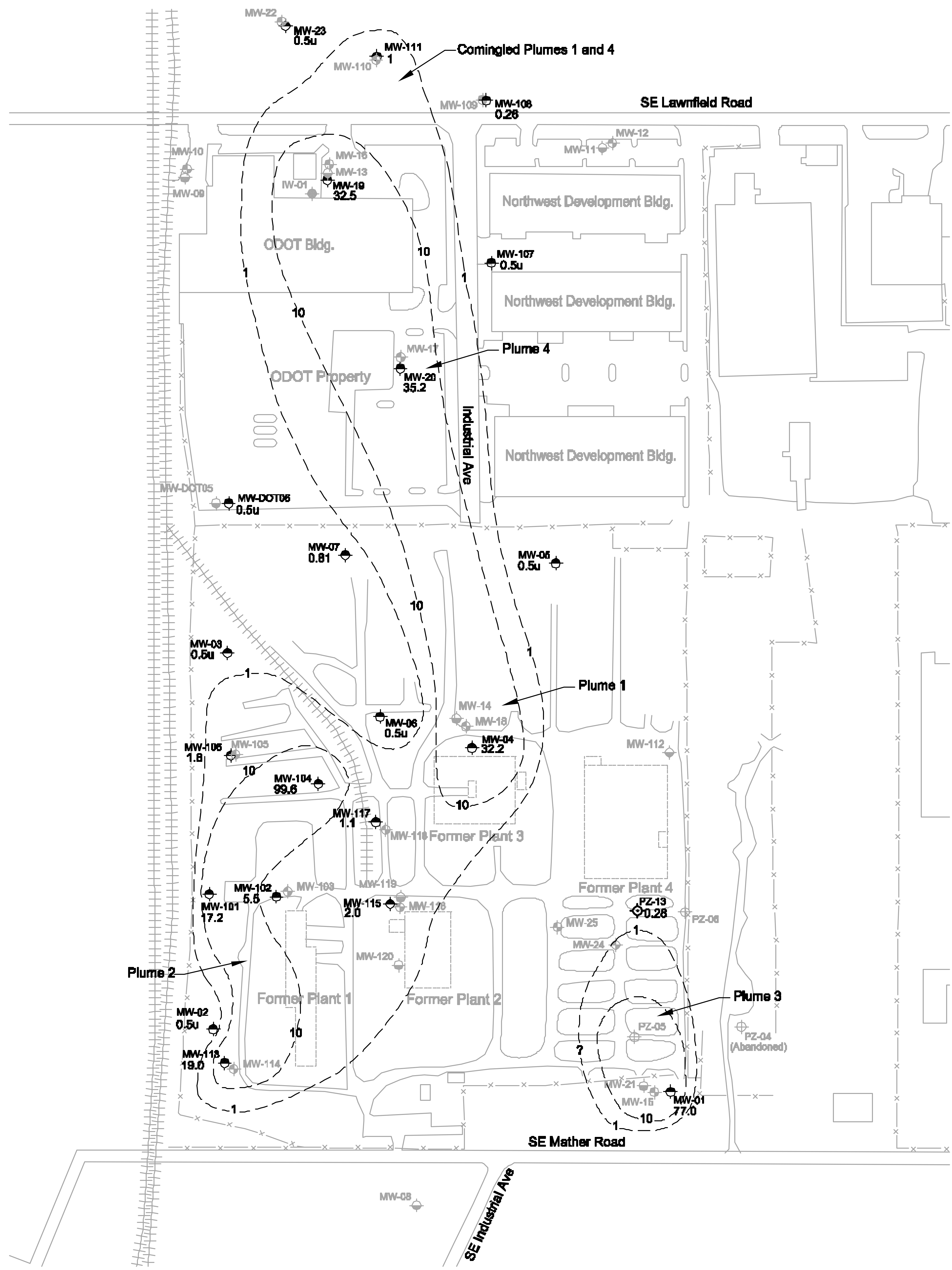
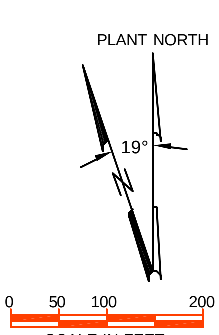
FIGURES



VICINITY MAP

URS	EPA REGION 10	GROUNDWATER OPERABLE UNIT 2	DRAWING NUMBER: FIGURE 1	
111 S.W. Columbia, Suite 900 Portland, Oregon 97201 (tel) 503-222-7200 (fax) 503-222-4292	NW PIPING & CASING / HALL PROCESS COMPANY	VICINITY MAP	CAD FILE NUMBER: C-01	
			SHEET: of	REV. B





LEGEND

- Shallow Upper Aquifer Well (0-20 feet bgs)
- Intermediate Upper Aquifer Well (20-60 feet bgs)
- Lower Upper Aquifer Well (60-110 feet bgs)
- Lower Aquifer Well (115 feet bgs)
- Shallow Upper Aquifer Piezometer (0-20 feet bgs)
- Intermediate Upper Aquifer Piezometer (20-60 feet bgs)

Groundwater Concentration & Contour Interval
Units in ug/L.

Figure 2
PCE Plume Boundary
Shallow Upper Aquifer
(Based on 2002 PCE Groundwater Concentrations)

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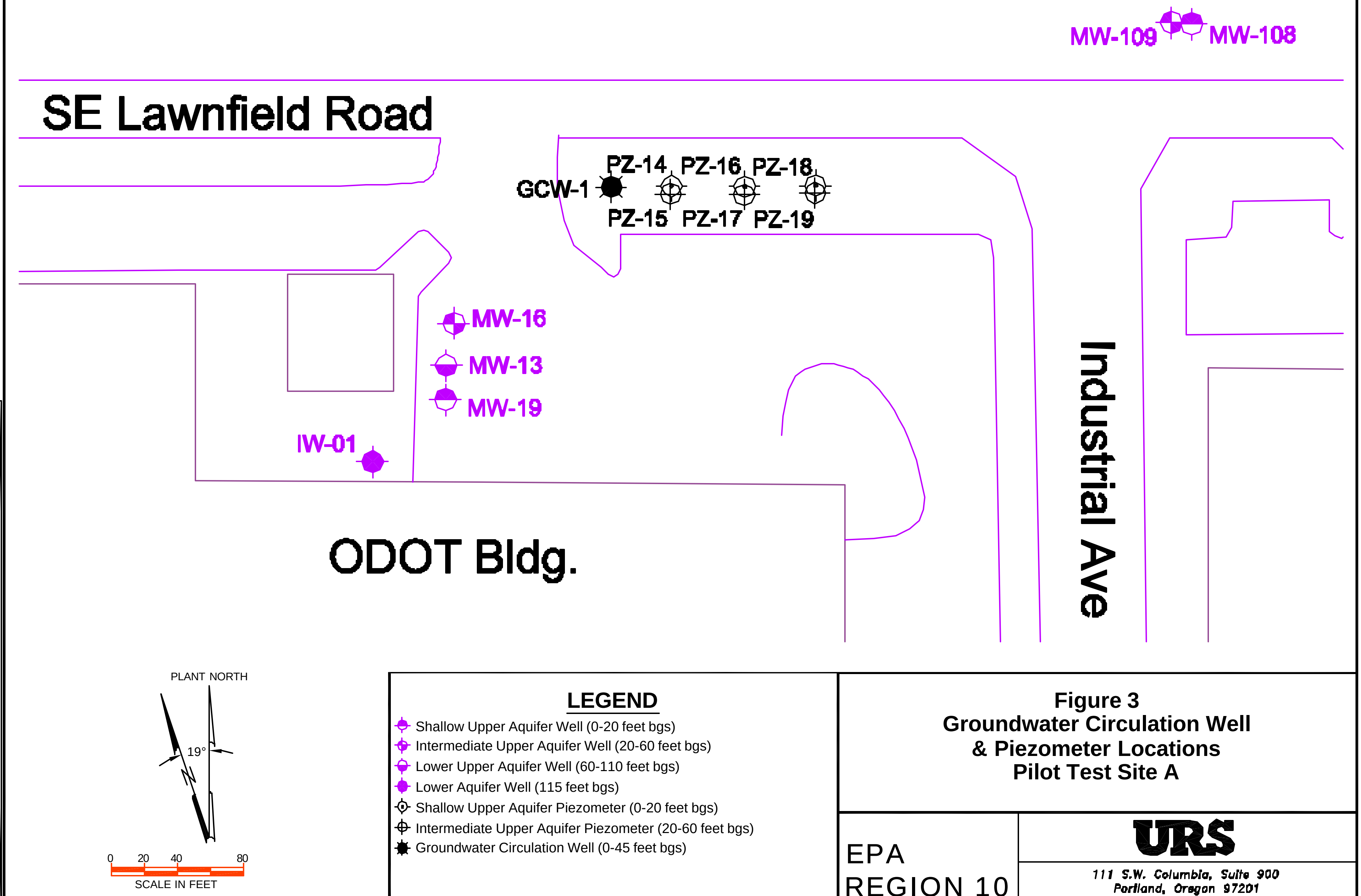

LEGEND

- Shallow Upper Aquifer Well (0-20 feet bgs)
- Intermediate Upper Aquifer Well (20-60 feet bgs)
- Lower Upper Aquifer Well (60-110 feet bgs)
- Lower Aquifer Well (115 feet bgs)
- Shallow Upper Aquifer Piezometer (0-20 feet bgs)
- Intermediate Upper Aquifer Piezometer (20-60 feet bgs)
- Groundwater Circulation Well (0-45 feet bgs)

Figure 3
Groundwater Circulation Well
& Piezometer Locations
Pilot Test Site A

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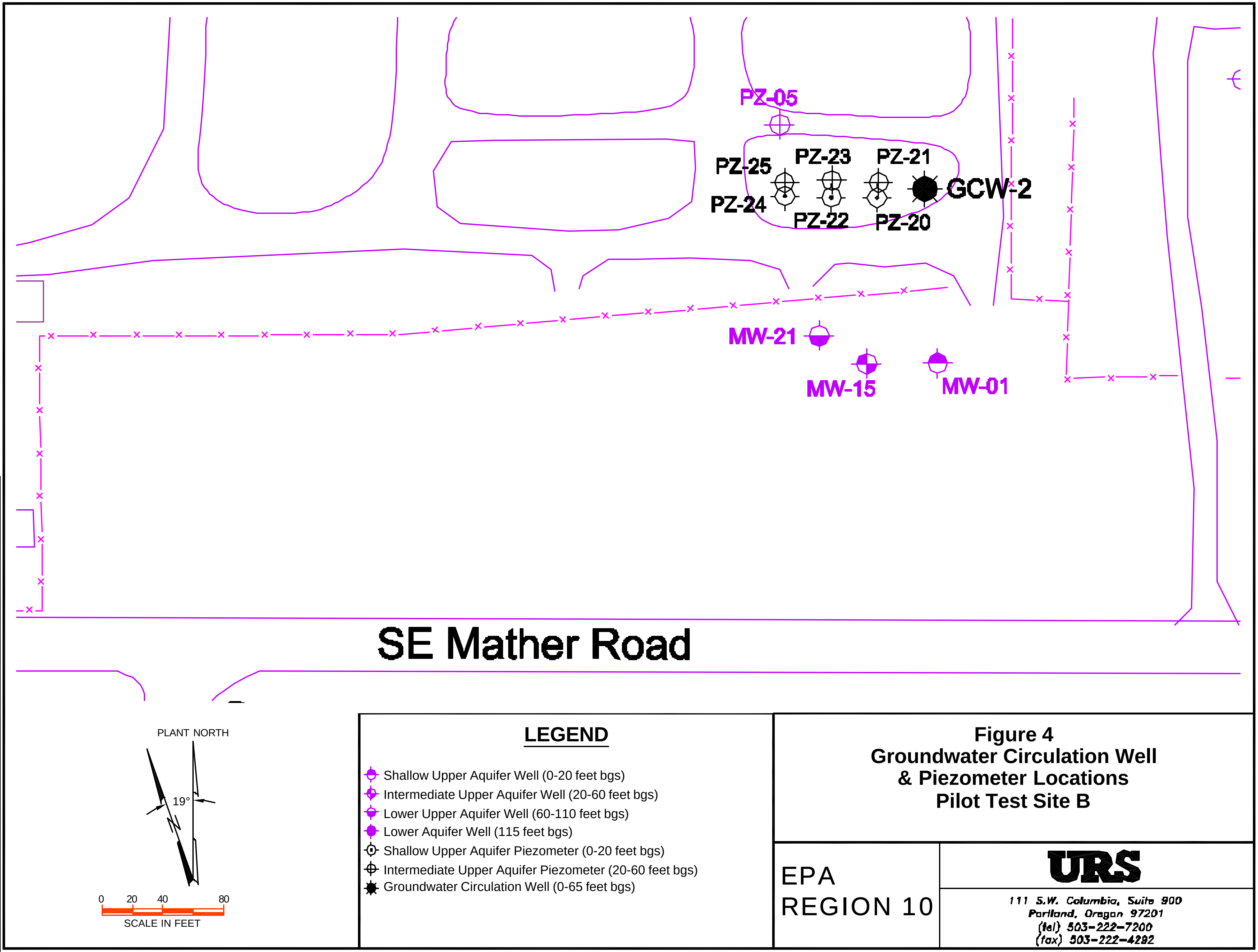

LEGEND

- Shallow Upper Aquifer Well (0-20 feet bgs)
- Intermediate Upper Aquifer Well (20-60 feet bgs)
- Lower Upper Aquifer Well (60-110 feet bgs)
- Lower Aquifer Well (115 feet bgs)
- Shallow Upper Aquifer Piezometer (0-20 feet bgs)
- Intermediate Upper Aquifer Piezometer (20-60 feet bgs)
- Groundwater Circulation Well (0-65 feet bgs)

Figure 4
Groundwater Circulation Well & Piezometer Locations
Pilot Test Site B

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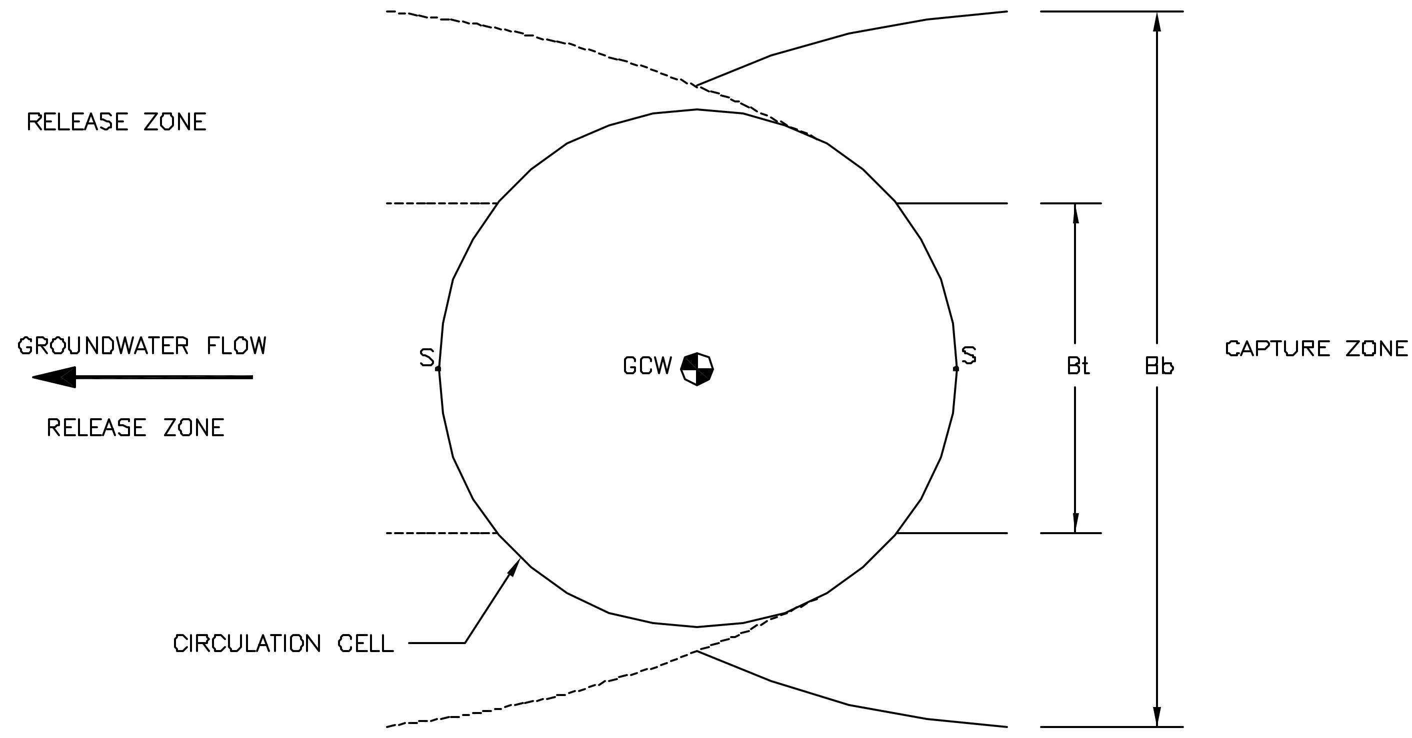

LEGEND:

Bt – WIDTH OF CAPTURE ZONE AT TOP

Bb – WIDTH OF CAPTURE ZONE AT BOTTOM

S – STAGNATION POINT

Figure 5
PLAN VIEW OF REVERSE FLOW CIRCULATION CELL, CAPTURE ZONE, & RELEASE ZONE OF A GCW

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Figure 6
%S and %(Bb + Bt)/4 Calculation for Commingled Plumes 1 through 4

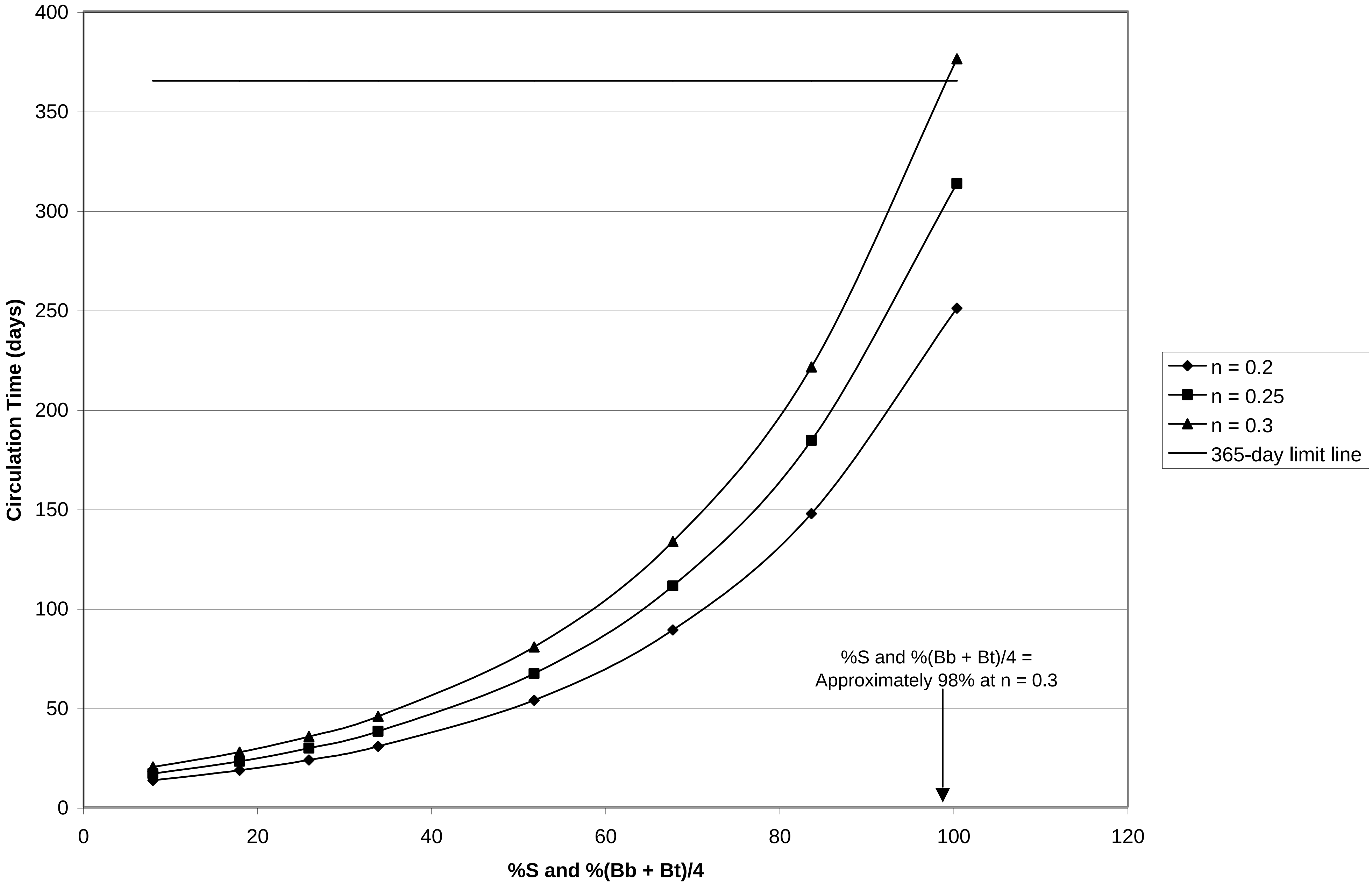

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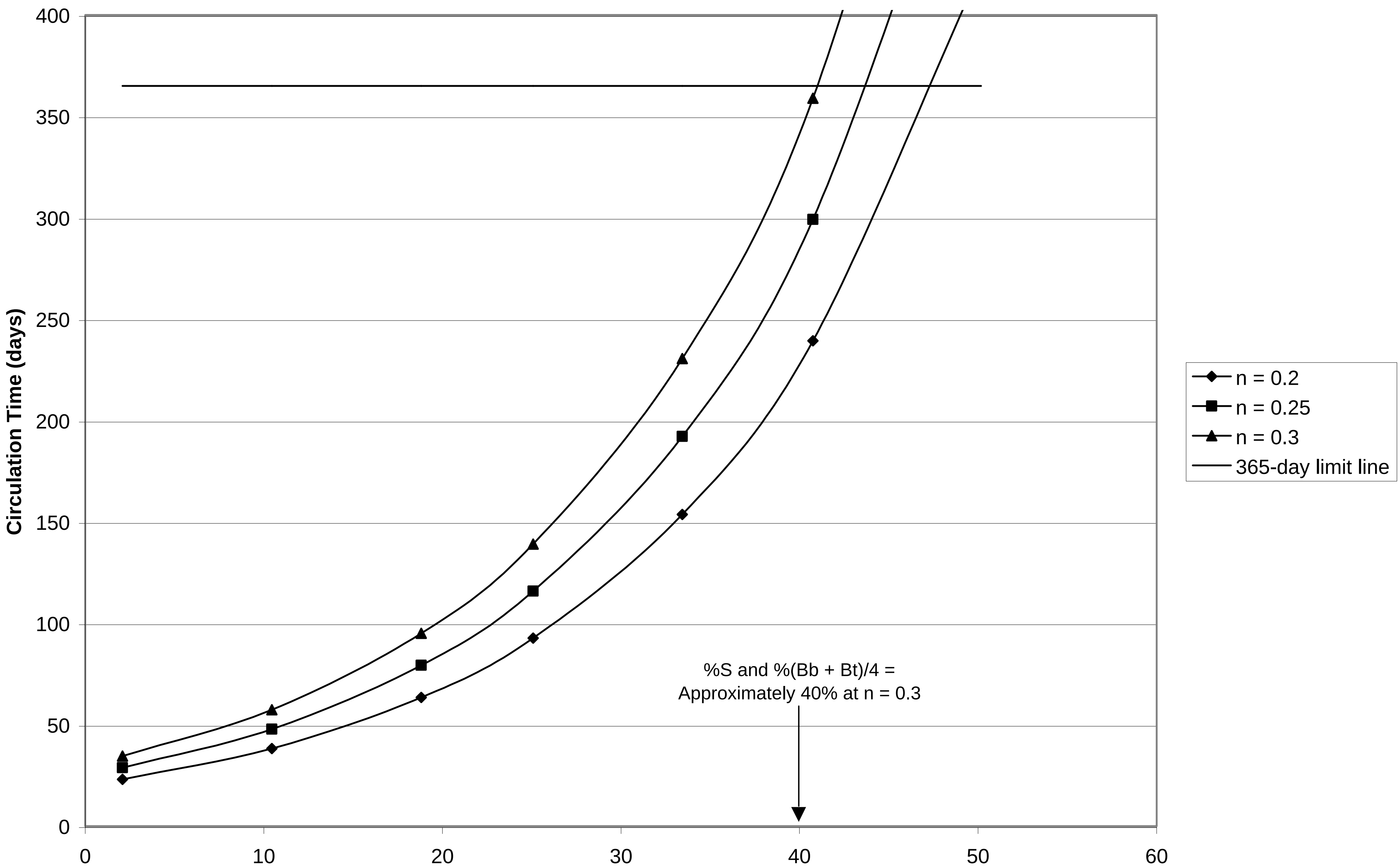
Figure 7
%S and %(Bb + Bt)/4 Calculation for Plume 3



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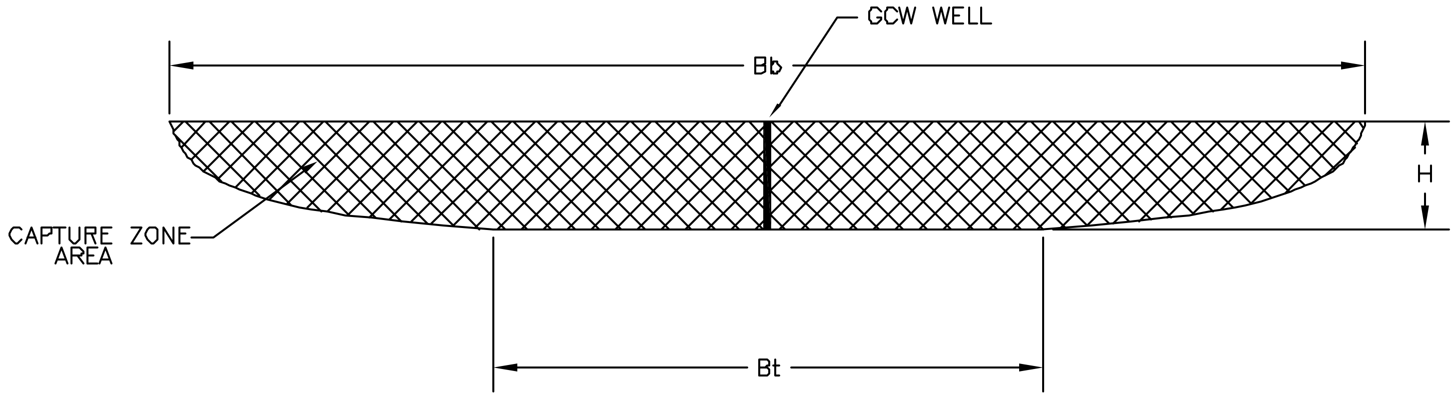

LEGEND:

B_t – WIDTH AT TOP

B_b – WIDTH AT BOTTOM

H – HEIGHT OF SATURATED ZONE TO BE TREATED

Figure 8
CAPTURE ZONE PERPENDICULAR TO GROUNDWATER FLOW OF SINGLE CELL REVERSE FLOW GCW

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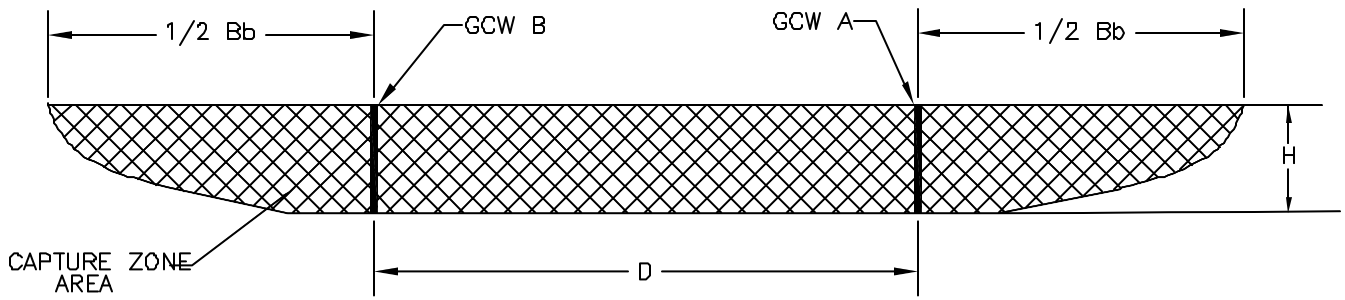

LEGEND:

D – CAPTURE ZONE BETWEEN TWO OR MORE GCWS

B_b+D – MAXIMUM CATURE ZONE FOR TWO OR MORE GCWS

H – HEIGHT OF SATURATED ZONE TO BE TREATED

Figure 9
CAPTURE ZONE PERPENDICULAR TO GROUNDWATER FLOW OF TWO REVERSE FLOW GCW

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TABLES

TABLE 1
Piezometer and Groundwater Circulation Well Construction Details

Piezometers									
Location ID	**Location**	**Total Depth (feet bgs)**	**Aquifer Level**	**Top of Screen Depth (feet bgs)**	**Bottom of Screen Depth (feet bgs)**	**Screen Length (feet)**	**Screen Slot Size (inches)1**	**Well Diameter (Inches)**	**Casing Material**
PZ-14	Leading Edge of Commingled Plumes 1 and 4	20	Shallow Upper	15	20	5	0.020	2	Sch 40 PVC
PZ-15	Leading Edge of Commingled Plumes 1 and 4	45	Intermediate Upper	40	45	5	0.020	2	Sch 40 PVC
PZ-16	Leading Edge of Commingled Plumes 1 and 4	20	Shallow Upper	15	20	5	0.020	2	Sch 40 PVC
PZ-17	Leading Edge of Commingled Plumes 1 and 4	45	Intermediate Upper	40	45	5	0.020	2	Sch 40 PVC
PZ-18	Leading Edge of Commingled Plumes 1 and 4	20	Shallow Upper	15	20	5	0.020	2	Sch 40 PVC
PZ-19	Leading Edge of Commingled Plumes 1 and 4	45	Intermediate Upper	40	45	5	0.020	2	Sch 40 PVC
PZ-20	Plume 3	20	Shallow Upper	15	20	5	0.020	2	Sch 40 PVC
PZ-21	Plume 3	65	Intermediate Upper	60	65	5	0.020	2	Sch 40 PVC
PZ-22	Plume 3	20	Shallow Upper	15	20	5	0.020	2	Sch 40 PVC
PZ-23	Plume 3	65	Intermediate Upper	60	65	5	0.020	2	Sch 40 PVC
PZ-24	Plume 3	20	Shallow Upper	15	20	5	0.020	2	Sch 40 PVC
PZ-25	Plume 3	65	Intermediate Upper	58	63	5	0.020	2	Sch 40 PVC
Groundwater Circulation Wells									
Location ID	**Location**	**Total Depth (feet bgs)**	**Aquifer Level**	**Upper Screen Depth Interval (feet bgs)**	**Lower Screen Depth Interval (feet bgs)**	**Screen Lengths (feet)**	**Screen Slot Size (inches)**	**Well Diameter (Inches)**	**Casing Material**
GCW-1	Leading Edge of Commingled Plumes 1 and 4	45	Shall Upper and Intermediate Upper	10 - 20	35 - 45	10	0.020	10	Low Carbon Steel
GCW-2	Plume 3	65	Shall Upper and Intermediate Upper	10 - 20	55 - 65	10	0.020	10	Sch 80 PVC

Notes:

(1) GCW well screens consist of Sch 80 stainless-steel Johnson V-Wire screen, with a 100-foot crush depth, and welded 480 threads to match the PVC casing threads. Piezometer screens consist of slotted PVC.
bgs - Below Ground Surface

TABLE 2
GCW-1 Zone of Influence Input Parameters

GCW-1 Input Parameters	Determination Method	Result
Gradient	Measurement	0.004
Upper Screen Length (saturated)	Construction	10 feet
Lower Screen Length	Construction	10 feet
Height of Cell	Construction	30 feet
Pumping Rate	Operational	25 liters per minute
Horizontal Hydraulic Conductivity	Empirical	4.0 x 10-3 cm/sec

TABLE 3
GCW-2 Zone of Influence Input Parameters

GCW-2 Input Parameters	Determination Method	Result
Gradient	Measurement	0.001
Upper Screen Length (saturated)	Construction	10 feet
Lower Screen Length	Construction	10 feet
Height of Cell	Construction	50 feet
Pumping Rate	Operational	70 liters per minute
Horizontal Hydraulic Conductivity	Empirical	1.2 x 10-3 cm/sec

TABLE 4
GCW-1 Zone of Influence Mathematical Determination
Input Parameters

GCW-1 ZOI Parameters	Result (feet)
S, Midpoint axis parallel to Flow	75
D, Capture Zone width Between Two or More GCWs	148
(Bb + Bt)/4, Midpoint axis perpendicular to Flow	74
Bt, Bottom Width of Capture Zone Trapezoid Reverse Flow GCW	64
Bb, Top Width of Capture Zone Trapezoid Reverse Flow GCW	233

TABLE 5
GCW-2 Zone of Influence Mathematical Determination
Input Parameters

GCW-2 ZOI Parameters	Result (feet)
S, Midpoint axis parallel to Flow	239
D, Capture Zone width Between Two or More GCWs	508
(Bb + Bt)/4, Midpoint axis perpendicular to Flow	254
Bt, Bottom Width of Capture Zone Trapezoid Reverse Flow GCW	371
Bb, Top Width of Capture Zone Trapezoid Reverse Flow GCW	645

Table 6
Practical ZOI Based on
GCW Time of Circulation

	GCW-1	**GCW-2**
%S	98	40
Practical ZOI based on %S	74 feet	96 feet
%(Bb + Bt)/4	98	40
Practical ZOI based on %(Bb + Bt)/4	73 feet	102 feet

TABLE 7
Ryznar Index Values Based on Historic and Recent Groundwater Data

Monitoring well	Date	Total Alkalinity (mg/l)	pH	TDS (mg/l)	Calcium Ion (mg/l)	S	C	Ryznar Index
Plume 3 MW-15	Mar-97	93	7.5	154	15	23.04	6.3	9.21
Plume 3 MW-15	10/11/2002	104	6.4	170	23.8	23.05	7.1	9.51
Plume 3 MW-15 (Duplicate)	10/11/2002	104	6.4	172	24.3	23.04	6.9	9.70
Plume 3 MW-1	Mar-97	182	7.5	230	30.3	23.07	7.4	8.11
Plume 1 MW-12	Mar-97	123	8.1	180	17.2	23.05	6.7	8.23
Plume 1MW-20	10/11/2002	150	6.4	247	43.6	23.08	7.7	9.94
Plume 1 MW-103	10/11/2002	122	7.6	186	25.2	23.05	7.0	8.49
Plume 1 MW-4	Mar-97	103	6.9	180	31.7	23.05	7.5	8.70
Plume 1 MW-4	10/11/2002	99	6.4	173	30.9	23.04	7.2	9.48
Worse Case Well MW-5	Mar-97	592	7.1	510	96.9	23.15	9.5	6.56

TABLE 8
Historic Groundwater Data
Dissolved Iron and Manganese

Monitoring Well	Date	Dissolved Iron (mg/l)	Dissolved Manganese (mg/l)	Total (mg/l)
Plume 3 MW-15	Mar-97	0.014	0.003	0.017
Plume 3 MW-1	Mar-97	0.348	0.221	0.569
Plume 1 MW-12	Mar-97	0.01	Non Detect	0.01
Plume 1 MW-20	Mar-97	0.426	2.51	2.936
Plume 1 MW-4	Mar-97	0.015	1.53	1.545
Worse Case Well MW-6	Mar-97	4.44	1.54	5.98

TABLE 9
Groundwater Circulation Well Operational Parameters

Operation Parameters	Preliminary Model				Pilot Test			
	Plume 1	Plume 2	Plume 3	Plume 4	Plume 1	Plume 2	Plume 3	Plume 4
Treatment Wall Parameters								
Pumping Rate (gpm)	20	--	--	20	6.6	--	--	6.6
(Bb + Bt)/4 (feet)	128	--	--	128	74	--	--	74
D Spacing (feet)	256	--	--	256	148	--	--	148
Source Reduction								
Pumping Rate (gpm)	20	20	20	20	6.6	--	18.5	6.6
Practical S (feet)	55	98	92	58	74	--	96	74
Well Spacing (feet)	110	196	184	116	148	--	192	148

Notes:
'-- Operational Parameters not calculated.

Project: NW Pipe & Casing OU 2 Remedial Design
Project Location: Clackamas, Oregon
Project Number: 33754161

Key to Log of Boring / Well

		SAMPLES						
Elevation feet	Depth, feet	Location	Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
1	2	3	4	5	6	7	8	9

COLUMN DESCRIPTIONS

1. **Elevation:** Elevation in feet referenced to mean sea level (MSL) or site datum.
2. **Depth:** Depth in feet below the ground surface.
3. **Sample Location:** Type of soil sample collected at approximate depth interval shown; sampler symbols are explained below.
4. **Sample Label:** Sample identification number.
5. **Drill Progress:** Time, in 24-hour clock, recorded at events during downhole advance such as sample collection, drill rod addition, down time, and daily start and finish.
6. **Graphic Log:** Graphic depiction of subsurface material encountered; typical symbols are explained below.
7. **Material Description:** Description of material encountered; may include color, moisture, grain size, and density/consistency.
8. **Well Schematic and Details:** Schematic of well installation; materials are described in the column to the right of the well schematic; graphic symbols are explained below.
9. **Field Notes:** Comments and observations regarding drilling, drill rig behavior, cuttings, sampling, or well construction and development made by driller or field personnel.

TYPICAL SOIL GRAPHIC SYMBOLS

- Poorly graded SAND (SP)
- Well-graded SAND (SW)
- SAND with silt (SP-SM)
- SILTY SAND (SM)
- CLAY (CL)
- SILT (ML)
- SANDY SILT (ML)
- CLAYEY SILT (ML)
- Poorly graded GRAVEL (GP)
- Well-graded GRAVEL (GW)
- GRAVEL with silt (GP-GM)
- SILTY GRAVEL (GM)

TYPICAL WELL GRAPHIC SYMBOLS

- Blank casing concrete
- Blank casing in filter sand
- Blank casing in cement-bentonite grout
- Slotted casing in filter sand
- Blank casing in bentonite chips
- Bentonite chip backfill

TYPICAL SAMPLER GRAPHIC SYMBOLS

- 2-inch-OD unlined split spoon (SPT)
- Shelby tube (thin-wall, fixed head)
- 2.5-inch-OD Modified California, four 4-inch brass liners
- Grab sample
- 2.5-inch-OD Lang split barrel, three 6-inch brass liners
- Bulk sample

OTHER GRAPHIC SYMBOLS

- First water encountered at time of drilling (ATD)
- Water level measured in well on specified date
- Change in material properties within a stratum
- Inferred contact between strata or gradational change in lithology

GENERAL NOTES

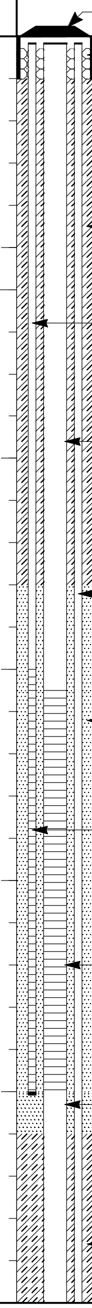
1. Soil classifications are based on the Unified Soil Classification System. Descriptions and stratum lines are interpretive; actual lithologic changes may be gradual. Field descriptions may have been modified to reflect results of lab tests.
2. Descriptions on these logs apply only at the specific boring locations and at the time the borings were advanced. They are not warranted to be representative of subsurface conditions at other locations or times.

Project: NW Pipe & Casing OU 2 Remedial Design **Project Location: Clackamas, Oregon** **Project Number: 33754161**	**Log of Boring / Well GCW-1** Sheet 1 of 2

Date(s) Drilled	**9/17/02 and 9/18/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary (dual-wall rotary)**	Drilling Contractor	**Tacoma Pump & Drilling**	Total Depth of Borehole	**46.0 feet**
Drill Rig Type	**Foremost DR-24**	Drill Bit Size/Type	**15-inch tricone bit (inner); 16-inch casing (outer)**	Top of Casing Elevation	**104.19 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**Not applicable**	Ground Surface Elevation	**104.83 feet MSL**
Water Level and Date Measured	**Not measured**	Borehole Completion	**Wells installed (see schematic): 10-in.-OD steel casing, screened 15.5-25 ft and 35.5-45 ft; two 1-1/4-in.-OD Sch. 40 PVC casings, screened 15-25 ft and 35-45 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	FIELD NOTES
	0			12:05 [9/17]		Slightly moist, dark gray, SILT with clay (ML), no gravel	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
100	5						
						Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~75% gravel consisting mostly of rounded basalt	
95	10						
						Becomes wet	
90	15						Borehole producing some water.
85	20			13:02			
80	25						
75	30						

WELL SCHEMATIC AND CONSTRUCTION DETAILS



Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	30					Wet, dark gray, GRAVEL with silt and sand (GP-GM), ~75% gravel consisting mostly of rounded basalt (continued)	Bentonite chips (26-32.5 ft)	
							Low carbon steel (Grade A-53) blank casing, 10-inch OD (25 to 35.5 ft)	
70	35			17:30 [9/17] 07:30 [9/18]			Sch. 40 PVC blank casing, 1-1/4-inch OD (0 to 35 ft)	
							10-20 silica sand filter pack (32.5-46 ft)	
65	40					Increasing silt content (driller's observation)	Johnson wire-wrapped stainless steel screen, 10-inch OD, 20-slot (35.5-45 ft)	Driller reports increasing silt. Boring not producing water.
							Sch. 40 PVC screen, 1-1/4-inch OD, 20-slot, hand slotted (35-45 ft)	
60	45			09:00				
						Boring completed to depth of 46 feet on 9/18/02.		
55	50							
50	55							
45	60							
40	65							

Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well GCW-2**
Project Location: Clackamas, Oregon	Sheet 1 of 2
Project Number: 33754161	

Date(s) Drilled	9/18/02 and 9/19/02	Logged By	D. Weatherby	Reviewer	D. Weatherby
Drilling Method	Air Rotary (dual-wall rotary)	Drilling Contractor	Tacoma Pump & Drilling	Total Depth of Borehole	65.0 feet
Drill Rig Type	Foremost DR-24	Drill Bit Size/Type	15-inch tricone bit (inner); 16-inch casing (outer)	Top of Casing Elevation	111.03 feet MSL
Sampling Method	No sampling performed	Hammer Data	Not applicable	Ground Surface Elevation	110.65 feet MSL
Water Level and Date Measured	Not measured	Borehole Completion	Wells installed (see schematic): 10-in.-OD steel casing, screened 15-25 ft and 55-65 ft; two 1-1/4-in.-OD Sch. 40 PVC casings, screened 15-25 ft and 55-65 ft		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	0			14:42 [9/18]		Slightly moist, dark gray, CLAYEY SILT (ML), trace gravel	Flush-mounted surface monument set in concrete; Concrete (0-1 ft); 16-inch-dia. borehole (0-65 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
110								
	4					Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt, variable silt and sand content	Bentonite chips (1-13 ft)	
105	5						Sch. 40 PVC blank casing, 1-1/4-inch OD (0 to 15 ft)	
100	10					Becomes wet	Sch. 40 PVC blank casing, 10-inch OD (0 to 15 ft); Sch. 40 PVC blank casing, 1-1/4-inch OD (0 to 55 ft)	
95	15						10-20 silica sand filter pack (13-26 ft); Sch. 40 PVC screen, 1-1/4-inch OD, 20-slot, hand slotted (15-25 ft)	Borehole producing some water.
90	20			15:13			Johnson wire-wrapped stainless steel screen, 10-inch OD, 20-slot (15-25 ft)	
85	25						Sch. 40 PVC blank casing, 10-inch OD (25 to 55 ft); Bentonite chips (26-53 ft)	
	30							

Project: NW Pipe & Casing OU 2 Remedial Design
Project Location: Clackamas, Oregon
Project Number: 33754161

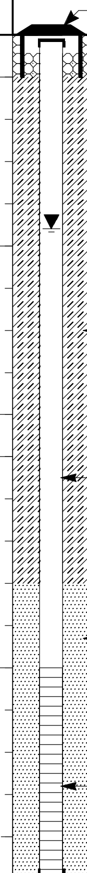
Log of Boring / Well GCW-2

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
80	30					Wet, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt, variable silt and sand content (continued)	16-inch-dia. borehole (0-65 ft)	
							Bentonite chips (26-53 ft)	
75	35						Sch. 40 PVC blank casing, 10-inch OD (25 to 55 ft)	
70	40						Sch. 40 PVC blank casing, 1-1/4-inch OD (0 to 55 ft)	
65	45			17:30 [9/18] 07:30 [9/19]				
60	50							
							10-20 silica sand filter pack (53-65 ft)	
55	55						Johnson wire-wrapped stainless steel screen, 10-inch OD, 20-slot (55-65 ft)	
50	60						Sch. 40 PVC screen, 1-1/4-inch OD, 20-slot, hand slotted (55-65 ft)	
								Driller reports boring producing 20-30 gpm water at 62.5 ft.
	65			10:40		**Boring completed to depth of 65 feet on 9/19/02.**		

Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-14**
Project Location: Clackamas, Oregon	Sheet 1 of 1
Project Number: 33754161	

Date(s) Drilled	8/27/02	Logged By	D. Weatherby	Reviewer	D. Weatherby
Drilling Method	Air Rotary	Drilling Contractor	R & R Drilling	Total Depth of Borehole	20.0 feet
Drill Rig Type	B-16 ODEX Rig	Drill Bit Size/Type	6-inch carbide underreemer	Top of Casing Elevation	104.76 feet MSL
Sampling Method	No sampling performed	Hammer Data	SD-5 air hammer	Ground Surface Elevation	105.11 feet MSL
Water Level and Date Measured	4.6 feet bgs on 9/3/02	Borehole Completion	Piezometer installed (see schematic): 2-in.-OD PVC casing screened 15-20 ft		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
105	0			14:05		Hard, dry, brown, SILT with gravel (ML)	Flush-mounted surface monument set in concrete; Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
						Slightly moist, dark gray, SILT with clay (ML), no gravel	6-inch-dia. borehole (0-20 ft)	
100	5						Bentonite chips (1-13 ft)	
95	10					Slightly moist, dark gray, GRAVEL with silt and SAND (GP-GM), ~75% gravel consisting of rounded basalt with minor quartzite	Sch. 40 PVC blank casing, 2-inch OD (0-15 ft)	
						Decreasing silt content	10-20 silica sand filter pack (13-20 ft)	
90	15					Becomes wet		Cuttings mixed with water at 15 ft.
							Sch. 40 PVC screen, 2-inch OD, 20-slot (15-20 ft)	
85	20			14:45		Wet, dark brown, GRAVEL with sand (GP), ~75% gravel consisting of rounded basalt with minor quartzite		
						Boring completed to depth of 20 feet on 8/27/02.		
80	25							
	30							



Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-15**
Project Location: Clackamas, Oregon	
Project Number: 33754161	Sheet 1 of 2

Date(s) Drilled	**8/28/02 and 8/29/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**45.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**104.74 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**104.94 feet MSL**
Water Level and Date Measured	**4.4 feet bgs on 9/3/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 40-45 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	0			07:26 [8/28]		Hard, dry, brown, SILT with gravel (ML)	Flush-mounted surface monument set in concrete; Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
						Slightly moist, dark gray, SILT with clay (ML), no gravel	6-inch-dia. borehole (0-45 ft)	
100	5							
						Slightly moist, dark gray, GRAVEL with silt and sand (GP-GM), ~75% gravel consisting of rounded basalt with minor quartzite	Bentonite chips (1-38 ft)	
95	10						Sch. 40 PVC blank casing, 2-inch OD (0-40 ft)	
						Becomes wet; decreasing silt content		Borehole producing water.
90	15							
						Wet, dark brown, GRAVEL with sand (GP), ~75% gravel consisting of rounded basalt with minor quartzite		
85	20							
80	25			08:45				
75	30							

Project: NW Pipe & Casing OU 2 Remedial Design Project Location: Clackamas, Oregon Project Number: 33754161	Log of Boring / Well PZ-15 Sheet 2 of 2

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	30					Wet, dark brown, GRAVEL with sand (GP), ~75% gravel consisting of rounded basalt with minor quartzite (continued)	6-inch-dia. borehole (0-45 ft)	
							Bentonite chips (1-38 ft)	Drill rig transmission blew, and drillers shut down for remainder of 8/28/02.
70	35			10:37 [8/28] 09:06 [8/29]			Sch. 40 PVC blank casing, 2-inch OD (0-40 ft)	Drill rig repair completed at 0900 on 8/29/02.
							10-20 silica sand filter pack (38-45 ft)	
65	40						Sch. 40 PVC screen, 2-inch OD, 20-slot (40-45 ft)	
60	45			11:45		**Boring completed to depth of 45 feet on 8/29/02.**		
55	50							
50	55							
45	60							
40	65							

Report: GEO_12W_PORT_AR; File: OU2REMED.GPJ; 10/25/2002 PZ-15

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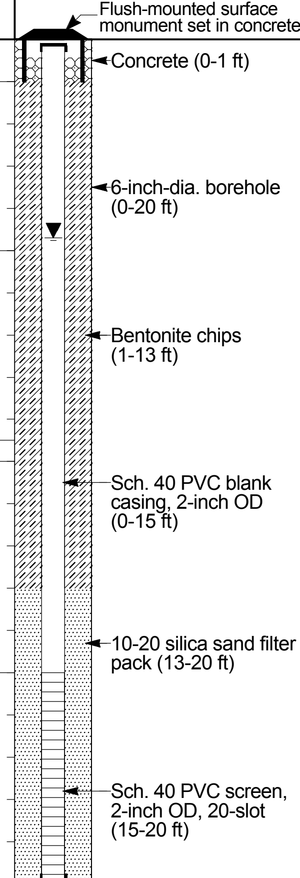
Project: NW Pipe & Casing OU 2 Remedial Design	# Log of Boring / Well PZ-16
Project Location: Clackamas, Oregon	Sheet 1 of 1
Project Number: 33754161	

Date(s) Drilled	**8/26/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**20.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**104.93 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**105.32 feet MSL**
Water Level and Date Measured	**4.7 feet bgs on 9/3/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 15-20 ft**		

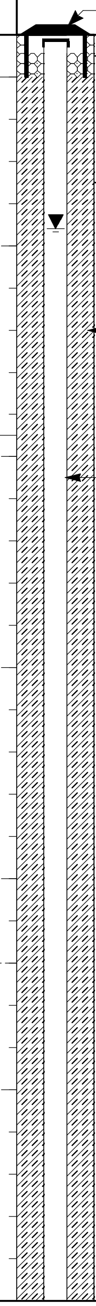
Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
105	0			13:40		Hard, dry, brown, SILT with gravel (ML)	Flush-mounted surface monument set in concrete; Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
						Slightly moist, dark gray, SILT with clay (ML), no gravel	6-inch-dia. borehole (0-20 ft)	
100	5						Bentonite chips (1-13 ft)	
95	10					Slightly moist, dark gray, GRAVEL with silt and sand (GP-GM), ~75% gravel to 1 inch consisting of subangular to subrounded basalt with minor quartzite	Sch. 40 PVC blank casing, 2-inch OD (0-15 ft)	
						Becomes moist; decreasing silt content	10-20 silica sand filter pack (13-20 ft)	
90	15					Becomes wet, dark brown		Cuttings mixed with water at 16 ft.
							Sch. 40 PVC screen, 2-inch OD, 20-slot (15-20 ft)	
85	20			14:30		**Boring completed to depth of 20 feet on 8/26/02.**		
80	25							
	30							



Project: NW Pipe & Casing OU 2 Remedial Design **Project Location: Clackamas, Oregon** **Project Number: 33754161**	**Log of Boring / Well PZ-17** Sheet 1 of 2

Date(s) Drilled	**8/27/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**45.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**104.81 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**105.09 feet MSL**
Water Level and Date Measured	**4.6 feet bgs on 9/3/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 40-45 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
105	0			07:30		Hard, dry, brown, SILT with gravel (ML)	Flush-mounted surface monument set in concrete; Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
						Slightly moist, dark gray, SILT with clay (ML), no gravel	6-inch-dia. borehole (0-45 ft)	
100	5						Bentonite chips (1-38 ft)	
95	10					Slightly moist, dark gray, GRAVEL with silt and sand (GP-GM), ~75% gravel to 1 inch consisting of subangular to subrounded basalt with minor quartzite	Sch. 40 PVC blank casing, 2-inch OD (0-40 ft)	
						Becomes moist; decreasing silt content with depth		
90	15					Becomes wet, dark brown		Cuttings mixed with water at 15 ft.
85	20			08:47				
						Wet, dark brown, GRAVEL with sand (GP), ~75% gravel consisting of rounded basalt with minor quartzite		
80	25							
	30			09:20				



Report: GEO_12W_PORT_AR; File: OU2REMED.GPJ; 10/25/2002 PZ-17

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Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-17**
Project Location: Clackamas, Oregon	Sheet 2 of 2
Project Number: 33754161	

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
75	30			09:20		Wet, dark brown, GRAVEL with sand (GP), ~75% gravel consisting of rounded basalt with minor quartzite (continued)	6-inch-dia. borehole (0-45 ft) Bentonite chips (1-38 ft) Sch. 40 PVC blank casing, 2-inch OD (0-40 ft) 10-20 silica sand filter pack (38-45 ft) Sch. 40 PVC screen, 2-inch OD, 20-slot (40-45 ft)	
70	35							
65	40							
60	45			11:42		**Boring completed to depth of 45 feet on 8/27/02.**		
55	50							
50	55							
45	60							
	65							

Report: GEO_12W_PORT_AR; File: OU2REMED.GPJ; 10/25/2002 PZ-17

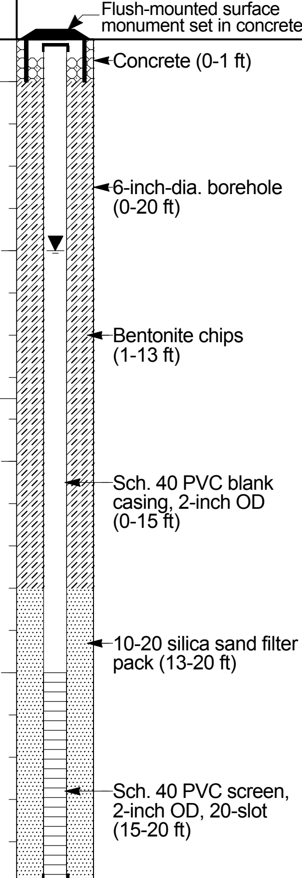
URS

Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-18**
Project Location: Clackamas, Oregon	Sheet 1 of 1
Project Number: 33754161	

Date(s) Drilled	**8/29/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**20.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**105.10 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**105.42 feet MSL**
Water Level and Date Measured	**5.0 feet bgs on 9/3/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 15-20 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	FIELD NOTES
105	0			13:20		Hard, dry, brown, SILT with gravel (ML)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
						Slightly moist, dark gray, SILT with clay (ML), no gravel	
100	5						
						Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~75% gravel to 1 inch consisting of rounded basalt with minor quartzite	
95	10						
						Becomes wet; decreasing silt content with depth	Borehole producing water.
90	15						
						Becomes dark brown	
85	20			14:25		**Boring completed to depth of 20 feet on 8/29/02.**	
80	25						
	30						

WELL SCHEMATIC AND CONSTRUCTION DETAILS



Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-19**
Project Location: Clackamas, Oregon	Sheet 1 of 2
Project Number: 33754161	

Date(s) Drilled	**8/29/02 and 9/3/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**45.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**104.89 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**105.18 feet MSL**
Water Level and Date Measured	**5.0 feet bgs on 9/3/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 40-45 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
105	0			16:05 [8/29]	Hard, dry, brown, SILT with gravel (ML)	Flush-mounted surface monument set in concrete; Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
	1				Slightly moist, dark gray, SILT with clay (ML), no gravel		
	3					6-inch-dia. borehole (0-45 ft)	
100	5						
	7				Becomes moist	Bentonite chips (1-38 ft)	
95	10					Sch. 40 PVC blank casing, 2-inch OD (0-40 ft)	
	11				Wet, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting of rounded basalt with minor quartzite		Borehole producing water.
90	15						
	17			16:44	Becomes dark brown		Borehole producing much less water compared to PZ-15 and PZ-17.
85	20						
80	25			18:00			
	30						

Project: NW Pipe & Casing OU 2 Remedial Design
Project Location: Clackamas, Oregon
Project Number: 33754161

Log of Boring / Well PZ-19

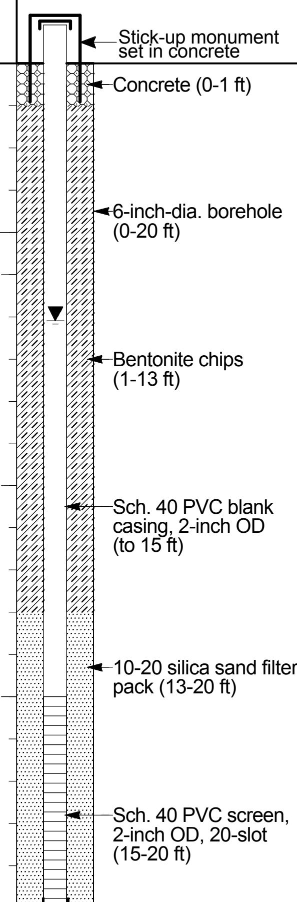
Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
75	30			18:00		Wet, dark brown, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting of rounded basalt with minor quartzite (continued)	6-inch-dia. borehole (0-45 ft) Bentonite chips (1-38 ft)	
70	35			19:20 [8/29] 08:00 [9/3]			Sch. 40 PVC blank casing, 2-inch OD (0-40 ft) 10-20 silica sand filter pack (38-45 ft)	Drill rig hydraulic line blew; drillers shut down for 8/29/02. Return to borehole and resume drilling on 9/3/02.
65	40			08:45			Sch. 40 PVC screen, 2-inch OD, 20-slot (40-45 ft)	
60	45					**Boring completed to depth of 45 feet on 9/3/02.**		
55	50							
50	55							
45	60							
	65							

Project: NW Pipe & Casing OU 2 Remedial Design
Project Location: Clackamas, Oregon
Project Number: 33754161

Log of Boring / Well PZ-20

Date(s) Drilled	**9/3/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**20.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**113.35 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**110.95 feet MSL**
Water Level and Date Measured	**6.1 feet bgs on 9/5/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 15-20 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	0			12:45		Slightly moist, dark gray, CLAYEY SILT (ML), trace gravel		No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
110								
						Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt		
	5							
105								
	10					Becomes wet, dark brown; decreasing silt content		
100								
	15							
95								
	20			13:43		**Boring completed to depth of 20 feet on 9/3/02.**		
90								
	25							
85								
	30							



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Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-21**
Project Location: Clackamas, Oregon	Sheet 1 of 2
Project Number: 33754161	

Date(s) Drilled	**9/12/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary (dual-wall rotary)**	Drilling Contractor	**Tacoma Pump & Drilling**	Total Depth of Borehole	**65.0 feet**
Drill Rig Type	**Foremost DR-24**	Drill Bit Size/Type	**5-inch tricone bit (inner); 6-inch casing (outer)**	Top of Casing Elevation	**113.55 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**Not applicable**	Ground Surface Elevation	**110.97 feet MSL**
Water Level and Date Measured	**Not measured**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 60-65 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	0			13:45		Slightly moist, dark gray, CLAYEY SILT (ML), trace gravel	Stick-up monument set in concrete; Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
110								
	4					Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt	6-inch-dia. borehole (0-65 ft)	
	5							
105							Bentonite chips (1-57 ft)	
	10					Becomes wet	Sch. 40 PVC blank casing, 2-inch OD (to 60 ft)	
100								
	15							Borehole producing water.
95								
	20			14:05				
90								
	25							
85								
	30							

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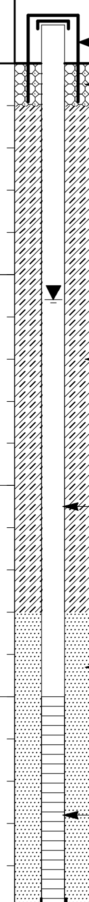
Elevation, feet	Depth, feet	SAMPLES Location	SAMPLES Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	30					Wet, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt (continued)		
80							6-inch-dia. borehole (0-65 ft)	
	35						Bentonite chips (1-57 ft)	
75							Sch. 40 PVC blank casing, 2-inch OD (to 60 ft)	
	40			14:26				
70								
	45							
65								
	50							
60								
	55							
55							10-20 silica sand filter pack (57-65 ft)	
	60			15:18				
50							Sch. 40 PVC screen, 2-inch OD, 20-slot (60-65 ft)	
	65			15:38		**Boring completed to depth of 65 feet on 9/12/02.**		

Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-22**
Project Location: Clackamas, Oregon	Sheet 1 of 1
Project Number: 33754161	

Date(s) Drilled	**9/3/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**20.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**113.12 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**110.55 feet MSL**
Water Level and Date Measured	**5.6 feet bgs on 9/5/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 15-20 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
110	0			15:05		Slightly moist, dark gray, CLAYEY SILT (ML), trace gravel	Stick-up monument set in concrete; Concrete (0-1 ft); 6-inch-dia. borehole (0-20 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
105	5					Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt	Bentonite chips (1-13 ft)	
100	10					Becomes wet, dark brown; decreasing silt content	Sch. 40 PVC blank casing, 2-inch OD (to 15 ft); 10-20 silica sand filter pack (13-20 ft)	
95	15						Sch. 40 PVC screen, 2-inch OD, 20-slot (15-20 ft)	Borehole producing water.
90	20			16:00		**Boring completed to depth of 20 feet on 9/3/02.**		
85	25							
	30							



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Project: NW Pipe & Casing OU 2 Remedial Design
Project Location: Clackamas, Oregon
Project Number: 33754161

Log of Boring / Well PZ-23

Date(s) Drilled	**9/12/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary (dual-wall rotary)**	Drilling Contractor	**Tacoma Pump & Drilling**	Total Depth of Borehole	**65.0 feet**
Drill Rig Type	**Foremost DR-24**	Drill Bit Size/Type	**5-inch tricone bit (inner); 6-inch casing (outer)**	Top of Casing Elevation	**113.11 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**Not applicable**	Ground Surface Elevation	**110.61 feet MSL**
Water Level and Date Measured	**Not measured**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 60-65 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
							Stick-up monument set in concrete	
110	0			07:55		Slightly moist, dark gray, CLAYEY SILT (ML), trace gravel	Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
							6-inch-dia. borehole (0-65 ft)	
105	5					Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt	Bentonite chips (1-52 ft)	
100	10					Becomes wet	Sch. 40 PVC blank casing, 2-inch OD (to 60 ft)	Borehole producing water.
95	15							
90	20			08:20				
85	25							
	30							

Project: NW Pipe & Casing OU 2 Remedial Design	**Log of Boring / Well PZ-23**
Project Location: Clackamas, Oregon	Sheet 2 of 2
Project Number: 33754161	

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	30					Wet, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt (continued)		
80							6-inch-dia. borehole (0-65 ft)	
	35						Bentonite chips (1-52 ft)	
75								
							Sch. 40 PVC blank casing, 2-inch OD (to 60 ft)	
	40			08:57				
70								
	45							
65								
	50							
60								
							10-20 silica sand filter pack (52-65 ft)	Driller inadvertently added too much filter sand.
	55							
55								
	60			09:26				
50							Sch. 40 PVC screen, 2-inch OD, 20-slot (60-65 ft)	
	65			09:53		**Boring completed to depth of 65 feet on 9/12/02.**		

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Project: NW Pipe & Casing OU 2 Remedial Design
Project Location: Clackamas, Oregon
Project Number: 33754161

Log of Boring / Well PZ-24

Date(s) Drilled	**9/3/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary**	Drilling Contractor	**R & R Drilling**	Total Depth of Borehole	**20.0 feet**
Drill Rig Type	**B-16 ODEX Rig**	Drill Bit Size/Type	**6-inch carbide underreemer**	Top of Casing Elevation	**113.65 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**SD-5 air hammer**	Ground Surface Elevation	**110.99 feet MSL**
Water Level and Date Measured	**5.8 feet bgs on 9/5/02**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 15-20 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
	0			17:20		Slightly moist, dark gray, CLAYEY SILT (ML), trace gravel	Stick-up monument set in concrete; Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
110							6-inch-dia. borehole (0-20 ft)	
	5					Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt		
105							Bentonite chips (1-13 ft)	
	10					Becomes wet, dark brown; decreasing silt content		
100							Sch. 40 PVC blank casing, 2-inch OD (to 15 ft)	
							10-20 silica sand filter pack (13-20 ft)	
	15							Borehole producing water.
95							Sch. 40 PVC screen, 2-inch OD, 20-slot (15-20 ft)	
	20					**Boring completed to depth of 20 feet on 9/3/02.**		
90								
	25							
85								
	30							

Project: NW Pipe & Casing OU 2 Remedial Design	Log of Boring / Well PZ-25
Project Location: Clackamas, Oregon	
Project Number: 33754161	Sheet 1 of 2

Date(s) Drilled	**9/11/02**	Logged By	**D. Weatherby**	Reviewer	**D. Weatherby**
Drilling Method	**Air Rotary (dual-wall rotary)**	Drilling Contractor	**Tacoma Pump & Drilling**	Total Depth of Borehole	**65.0 feet**
Drill Rig Type	**Foremost DR-24**	Drill Bit Size/Type	**5-inch tricone bit (inner); 6-inch casing (outer)**	Top of Casing Elevation	**113.29 feet MSL**
Sampling Method	**No sampling performed**	Hammer Data	**Not applicable**	Ground Surface Elevation	**110.76 feet MSL**
Water Level and Date Measured	**Not measured**	Borehole Completion	**Piezometer installed (see schematic): 2-in.-OD PVC casing screened 58-63 ft**		

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
							Stick-up monument set in concrete	
110	0			11:15		Slightly moist, dark gray, CLAYEY SILT (ML), trace gravel	Concrete (0-1 ft)	No soil samples collected. Material descriptions based on drill cuttings and drilling observations.
							6-inch-dia. borehole (0-65 ft)	
105	5					Moist, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt	Bentonite chips (1-55 ft)	
100	10					Becomes wet	Sch. 40 PVC blank casing, 2-inch OD (to 58 ft)	Borehole beginning to produce water.
95	15							
90	20			11:25				
85	25							
	30							

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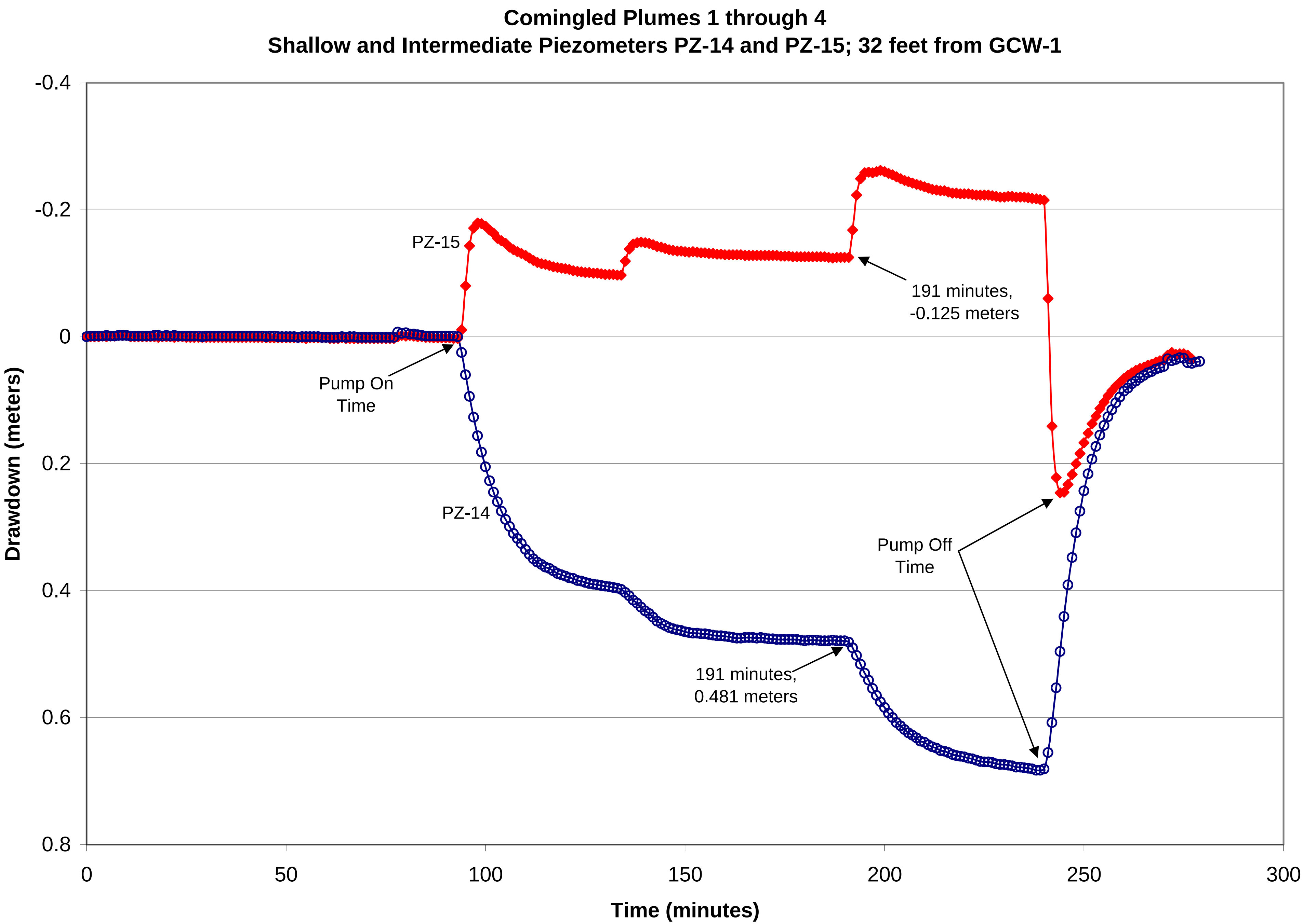
Project: NW Pipe & Casing OU 2 Remedial Design
Project Location: Clackamas, Oregon
Project Number: 33754161

Log of Boring / Well PZ-25

Elevation, feet	Depth, feet	SAMPLES: Location	SAMPLES: Sample Label	Drill Progress, 24-hour clock	Graphic Log	MATERIAL DESCRIPTION	WELL SCHEMATIC AND CONSTRUCTION DETAILS	FIELD NOTES
80	30					Wet, dark gray, GRAVEL with silt and sand (GP-GM), ~80% gravel consisting mostly of rounded basalt (continued)	6-inch-dia. borehole (0-65 ft)	
75	35						Bentonite chips (1-55 ft)	
							Sch. 40 PVC blank casing, 2-inch OD (to 58 ft)	
70	40			12:15				
65	45							
60	50							
55	55						10-20 silica sand filter pack (55-65 ft)	
50	60			13:00			Sch. 40 PVC screen, 2-inch OD, 20-slot (58-63 ft)	
						Wet, dark gray SILT (ML)		
	65			13:23		**Boring completed to depth of 65 feet on 9/11/02.**		



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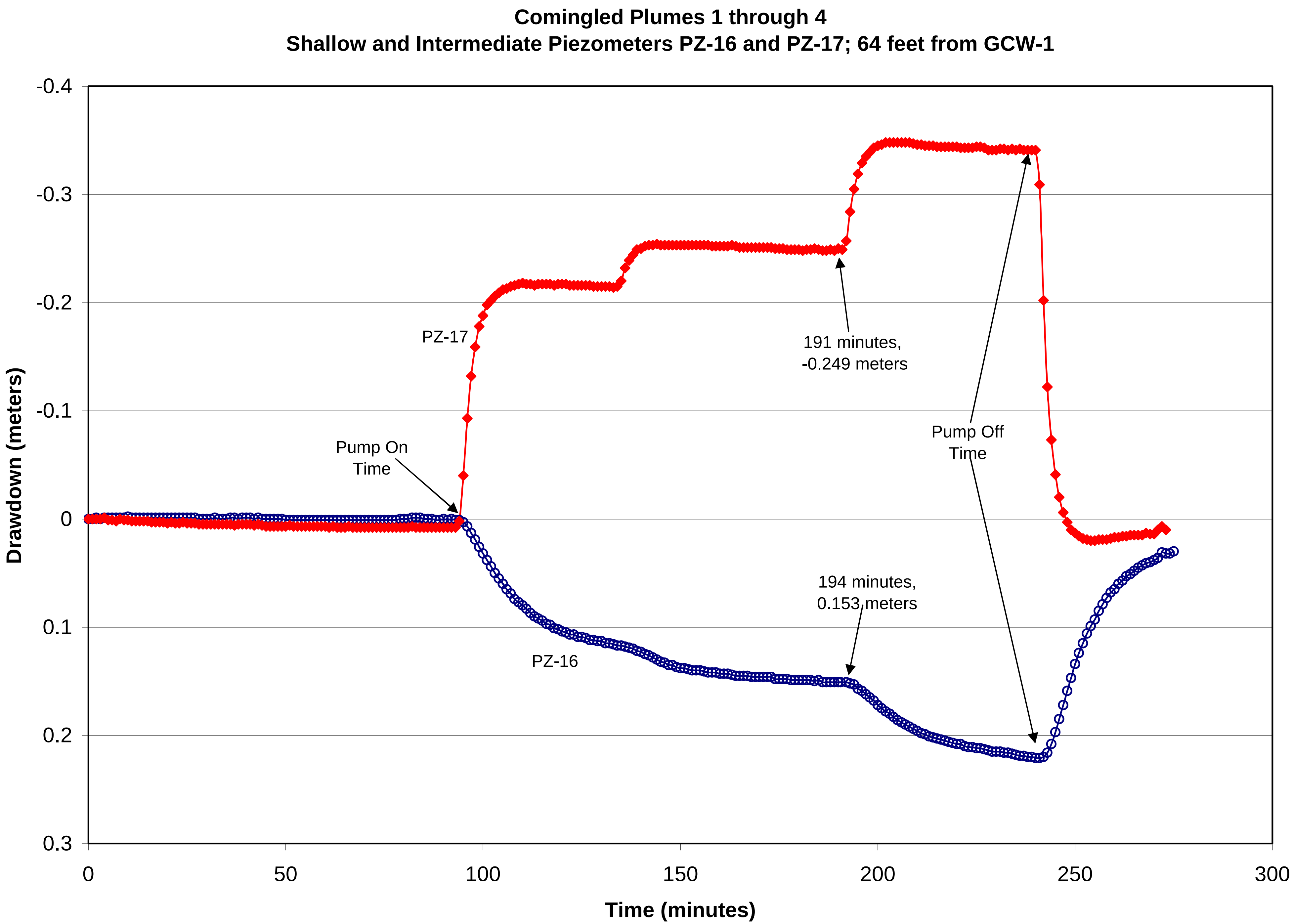

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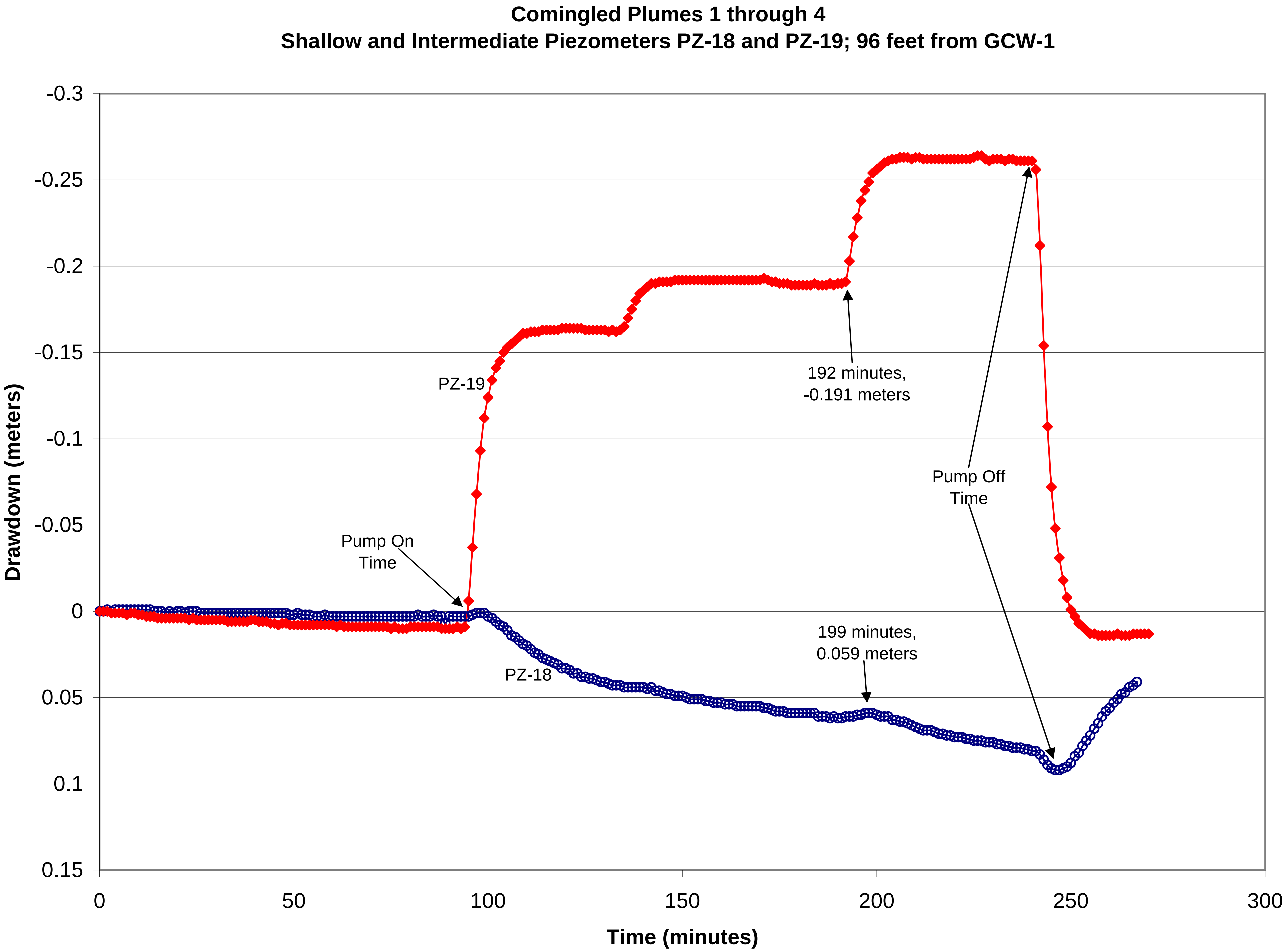

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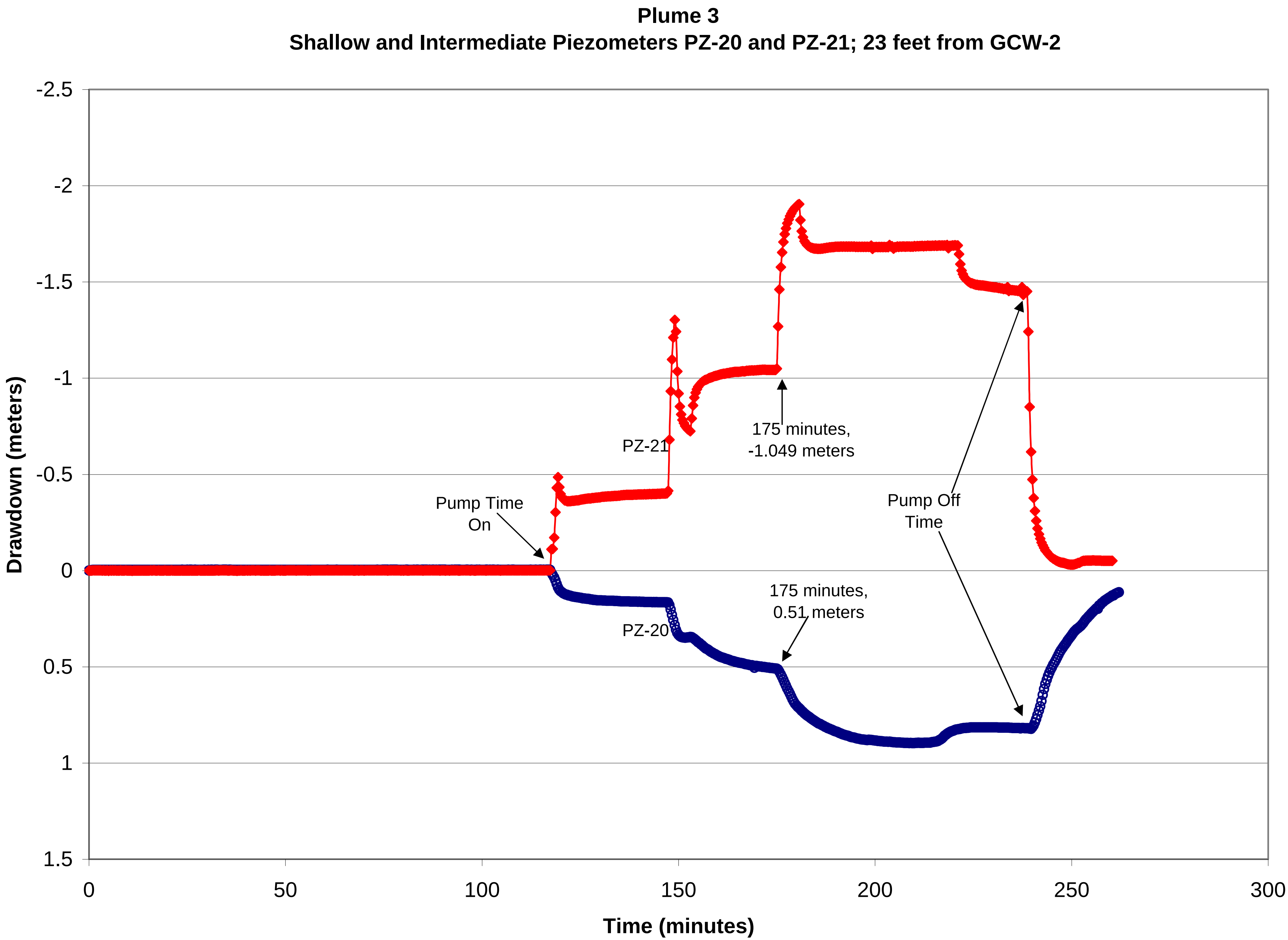

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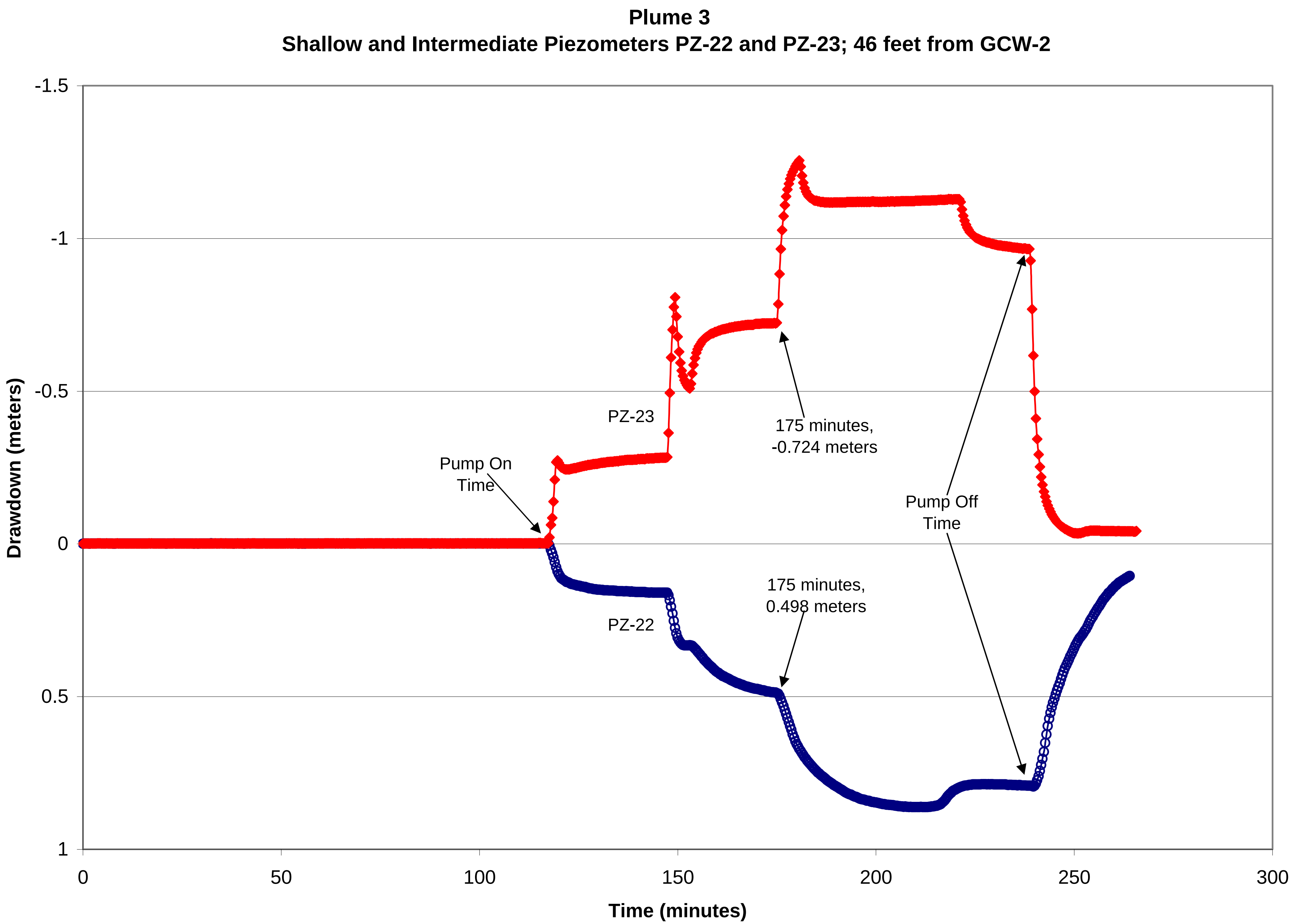

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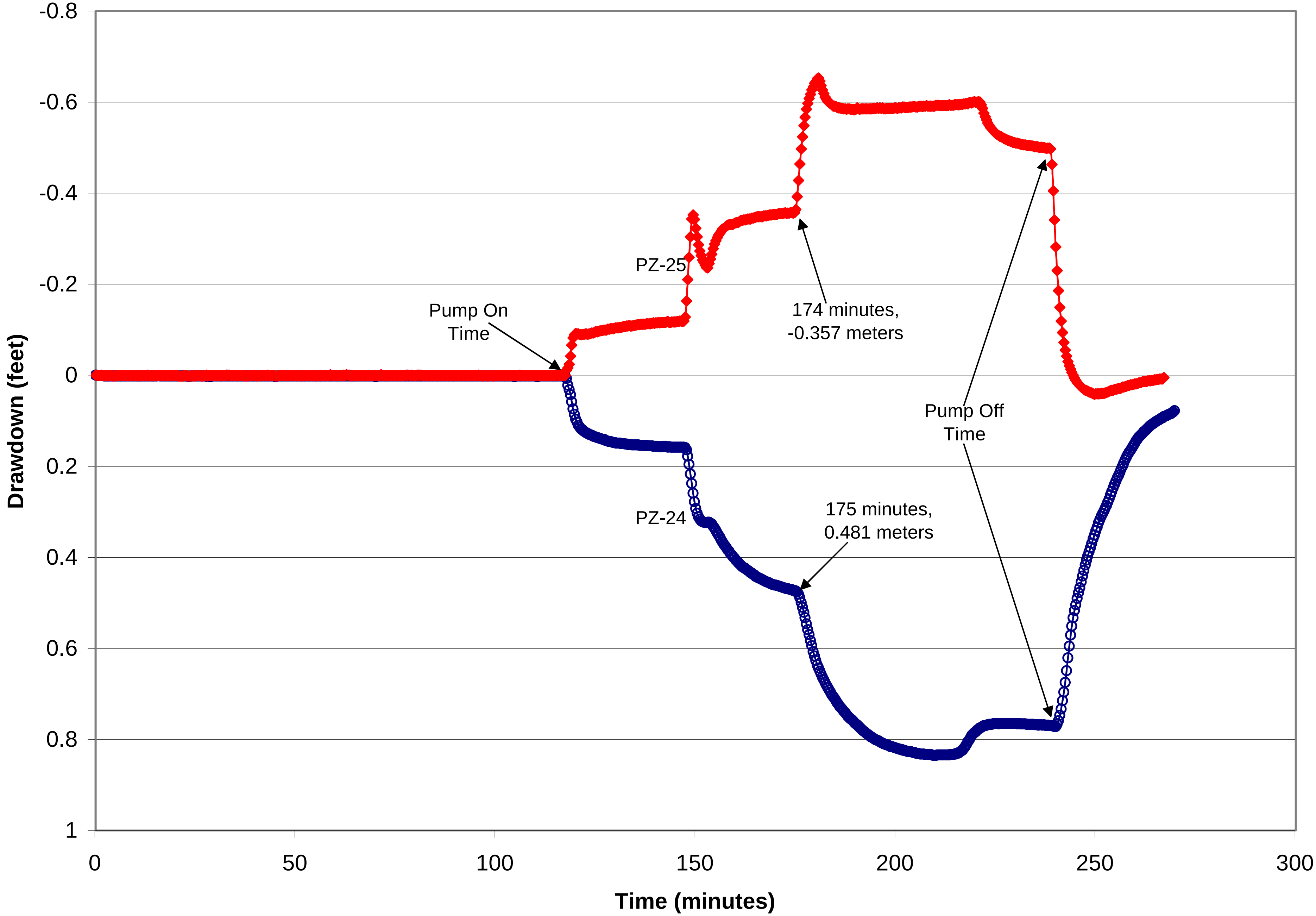
Plume 3
Shallow and Intermediate Piezometers PZ-24 and PZ-25; 69 feet from GCW-2



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